Water-Supply and Irrigation Paper No. 188

Series { B, Descriptive Geology, 108
O, Underground Waters, 66 }

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, Director

WATER RESOURCES

OF THE

RIO GRANDE VALLEY IN NEW MEXICO

AND THEIR DEVELOPMENT

BY

WILLIS T. LEE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1907

Water-Supply and Irrigation Paper No. 188

Series { B, Descriptive Geology, 108
0, Underground Waters, 66

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

WATER RESOURCES

OF THE

RIO GRANDE VALLEY IN NEW MEXICO

AND THEIR DEVELOPMENT

BY

WILLIS T. LEE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1907

CONTENTS.

ILLUSTRATIONS.


TOPOGRAPHIC SKETCH MAP
OF THE
RIO GRANDE REGION
NEW MEXICO
Compiled from U. S. G. S. topographic maps and field surveys by Willis T. Lee
Scale
10 0 10 20 30 Miles
10 0 10 20 30 40 50 Kilometers
Figures indicate elevations in feet above mean sea level
1906
Artesian wells – flowing
Artesian wells – non-flowing
Wells with no artesian pressure
107° 00'
106° 00'
36°
35°
34°
33°
32°
JEMES MTS.
ESPANOLA VALLEY
Ildefonso
ROCKY MOUNTAINS
White Rock Canyon
SANTA FE
6947
Santa Fe Cr.
Glorieta Pass
SANTO DOMINGO VALLEY
San Felipe Canyon
Santo Domingo
Galisteo Cr.
Glorieta Mesa
Rio Jemes
Bernalillo
5042
SANDIA MTS.
ALBUQUERQUE VALLEY
4943
Albuquerque
Isleta
4885
MANZANO RANGE
Sandia
Rio Puerco
Belen
4794
Colorado
Becker
5160
SIERRA LADRON
Arroyo Salado
Rio Grande
BELEN VALLEY
San Acacia
CERRO MONTOSO
SOCORRO MTS.
Socorro
4579
MAGDALENA MTS.
SAN MATEO MTS.
SOCORRO VALLEY
Chupadera Mesa
SIERRA OSCURA
San Marcial
4447
ENGLE RESERVOIR SITE
FRA CRISTOBAL RANGE
Engle
Elephant Butte
4674
CERRO CUCHILLO
Las Palomas
Mescal Canyon
CABALLOS MTS.
Aleman
4655
Upham
JORNADA DEL MUERTO
SAN ANDREAS RANGE
Rincon
4051
CERRO MAGDALENA
Old Fort Selden
CERRO ROBLEDO
DONA ANA HILLS
Picacho Pk.
Las Cruces
3883
Tortuga
ORGAN MTS.
Bosque Seco
MESILLA VALLEY
Volcanoes
Lanark
4156
POTRILLO MTS.
FRANKLIN MTS.
NEW MEXICO
TEXAS
BOUNDARY LINE
NEW MEXICO
MEXICO
4114
Noria
3680
Rodadero Pk.
El Paso
EL PASO VALLEY

WATER RESOURCES OF THE RIO GRANDE VALLEY IN NEW MEXICO, AND THEIR DEVELOPMENT.

By Willis T. Lee.

INTRODUCTION.

The investigations described in this paper were undertaken for the purpose of gathering information which might aid in the development of the water resources of the Rio Grande Valley in New Mexico. Two general lines of observations were followed, one pertaining to underground waters and their utilization, the other to the storage and conservation of the surface waters. The work was done during the field seasons of 1904 and 1905 under the general direction of Mr. N. H. Darton. The area examined extends along the Rio Grande from the southern boundary of New Mexico northward to Santa Fe.

The valley of the Rio Grande, lying west of the Rocky Mountain uplift, extends in a north-south direction through a part of New Mexico which is characterized by comparatively small and more or less isolated mountain groups separated by basinlike depressions partly filled with rock débris. The valley is a part of the semiarid region of the southwestern part of the United States, in which the rainfall is insufficient for agriculture without irrigation.

A comparatively small amount of the water derived from the mountains to the north sustains a small but permanent flow in the river in the northern part of the region, but this water gradually disappears and the river bed in the southern part is often dry.

The Rio Grande is essentially a storm-water stream, subject to great and sudden floods. Within the area described only three permanent streams—the Rio Puerco, Rio Jemes, and Galisteo Creek—enter the Rio Grande, and their discharge, except in times of storm, is comparatively small. The rainfall in the region occurs principally in the form of violent showers or "cloud-bursts," which fill the dry stream courses with turbulent floods of short duration. When these showers occur simultaneously in many parts of the region they cause more or less destructive floods in the river. For these reasons the fertile irrigable lands along the river are sometimes unproductive for want of water and at other times crops are ruined because the fields are submerged or irrigation ditches destroyed by floods.

Much of the diminution in the volume of flow downstream is due to the fact that a large part of the water of the river sinks beneath the surface into the porous material of the valley bottom. Many of the tributary stream courses that are dry where they join the river contain flowing water in their upper reaches, the water sinking beneath the surface when it reaches the detrital material of the valley. The water entering the ground from the river and from the tributary streams is sufficient in volume to warrant its development for irrigation.

GEOGRAPHY.

RELATION TO OTHER REGIONS.

New Mexico consists of four general geographic provinces—the plains, occupying its eastern part; the Rocky Mountain province occupying its central part; the plateau province, in its northwestern part; and the basin range province, in its southwestern part. The Rocky Mountains proper terminate in northern New Mexico, but the general mountain uplift extends southward across the Territory as a succession of comparatively small mountain groups. These have not been generally recognized as parts of the Rocky Mountains, altho they belong to the same general system. The Rio Grande region lies between the Rocky Mountain province on the east and the plateau and basin range provinces on the west.

EASTERN MARGIN.

The crest of the Rocky Mountain uplift, consisting of the southern extremity of the Rocky Mountains proper, the Sandia and Montoso mountains, Sierra Oscura, San Andreas Range, and the Organ and Franklin mountains, form the eastern boundary of the area here described. The uplift becomes progressively lower toward the south, the maximum altitudes varying from 13,000 feet in the Rocky Mountains east of Santa Fe to 7,000 feet in the Franklin Mountains in the southern part of the region, and the minimum altitudes from 7,500 feet in Glorietta Pass near the northern end of the region to 3,700 feet at the southern end where the Rio Grande cuts through the uplift at The Pass. The rocks consist of granites and sedimentary rocks that range in age from pre-Cambrian to Tertiary.

WESTERN MARGIN.

The western margin of the Rio Grande Valley is much more irregular than the eastern margin, in both outline and altitude. It is formed by the Jemes Mountains at the north, by the Ladron, Socorro, Magdalena, and San Mateo mountains in the central part, and by the

Good Sight and Potrillo mountains farther south. These groups are more or less widely separated, either by undrained detrital plains like La Mesa, lying between the Potrillo Mountains and Cerro Magdalen, or by broad valleys like that of the Rio Puerco.

The older sedimentary formations extend over the same wide range of geologic age as those in the eastern margin, but the exposures are small, the greater part of the surface being occupied by effusive rock and unconsolidated detritus.

CENTRAL AREA.

MOUNTAINS.

Three large groups of mountains, the Caballos, the Fra Cristobal, and Cerro Magdalen (not to be confused with the Magdalena Mountains) occur within the limits of the Rio Grande region, and several small groups and isolated peaks, like the Dona Ana Hills, Cerro Robledo, and Cerro Cuchillo.

The Caballos and Fra Cristobal ranges consist of granite and overlying sediments dipping eastward beneath the Jornada del Muerto. (Pl. VI, *B*.) The Socorro Mountains, Cerro Magdalen, the Dona Ana Hills, and a large number of smaller hills in the central part of the region are of eruptive origin, but many of the hills, such as Cerro Robledo (see Pl. III), Tortuga, Cerro Cuchillo, and Sierra Ladron, are tilted blocks of sedimentary rocks.

PLAINS.

In the southern half of the Rio Grande region there are two broad plains, which, on account of their important bearing on questions connected with underground-water conditions in the Rio Grande region, require special description. These are the Jornada del Muerto and La Mesa. The Jornada has been described in a former water-supply paper,[a] but certain characters directly affecting the problems here discust require further consideration.

In the paper above cited[b] the Jornada del Muerto is regarded as including Mesilla Valley on the south and the plain lying northeast of San Marcial between Sierra Oscura and Cerro Montoso, thus comprising an area having a length of about 200 miles and an average gradient of 12 feet per mile. This extension of the Jornada proper may be advisable in describing the structural geology, but it is thought best to use here the name in its original meaning, applying it only to the high plain between Las Cruces and San Marcial, since, thus defined, it corresponds not only with the local usage but also with the ancient course of the Rio Grande described on page 21.

[a] Keyes, C. R., Water-Sup. and Irr. Paper No. 123, U. S. Geol. Survey, 1905.
[b] Ibid., p. 13.

The Jornada del Muerto, according to this usage, is the nearly level detrital plain, 10 to 20 miles or more in width, extending from San Marcial southward to Las Cruces, between the San Andreas and the Caballos-Fra Cristobal mountain ranges—a distance of about 100 miles. It has no drainage lines except at the southern end, near the river, but throughout its length slight depressions occur near its center, in which storm waters gather and form small temporary lakes. The altitude of the plain at the northern end, near San Marcial, is about 4,700 feet, and at its southern end 4,250 feet, a difference in surface elevation of 450 feet in the 100 miles of length, or an average gradient of 4.5 feet per mile.

The rocks exposed in the mountain slopes on either side of the Jornada are the upturned sedimentary rocks forming the floor of the syncline described by Keyes in the report previously referred to. The central plain, however, is covered to a depth of at least several hundred feet with detritus, consisting of sand, gravel, and angular rock débris. As indicated by well records, the material in the central part of the Jornada is largely sand and rounded pebbles of quartzite and argillite, while angular detritus, consisting mainly of limestone and sandstone, is apparently more abundant near the sides.

The second plain, locally known as "La Mesa," lies in the southern part of the Rio Grande region west of Mesilla Valley, and extends from the vicinity of Las Cruces southward into Mexico. It is similar to the Jornada in many ways. Its altitude is the same as that of the southern end of the Jornada, and the two formed a single plain previous to the excavation of Mesilla Valley. La Mesa has a width of 20 miles or more and is undissected by erosion and entirely wanting in lines of surface drainage. It contains several broad, shallow depressions, but, unlike those of the Jornada, these do not retain storm waters for any appreciable length of time. Although inclined slightly to the south, the surface appears practically level over an area of more than 1,000 square miles.

To a depth of at least 945 feet, the depth of the deepest well, the material in La Mesa consists of clay, sand, and rounded pebbles of quartzite, argillite, and a great variety of hard igneous and metamorphic rocks, with a subordinate amount of angular débris. The surface is notably more sandy than that of the Jornada, and wells sunk in it encounter a greater proportion of fine material than occurs in the Jornada.

In the northern part of La Mesa there are gravel beds of considerable size at the surface, but these become less numerous toward the south, until near the Mexican boundary sand alone is exposed and the surface becomes practically level. The region was not explored south of the Mexican boundary for the purposes of this report, but from the summit of the Potrillo Mountains the sandy plain appeared to continue southward unbroken as far as the eye could reach. It is probable that La Mesa is the northern extremity of the broad interior basin of northern Mexico, the lowest parts of which, containing undrained lakes, occur 25 to 50 miles south of the international boundary. At some former time this basin was probably occupied by a large lake, the northern extremity of which covered La Mesa.

SLOPES.

The greater part of the surface of the Rio Grande region is made up of long, corrugated slopes, extending from the bordering mountains to the river. East of the river the slope varies in length from 5 to 20 miles. Near Santa Fe it is 12 miles long and has an average gradient of 125 feet per mile. East of Albuquerque it is about 10 miles long and has a gradient of about 70 feet per mile, and east of Las Cruces it is 10 miles long and has a gradient of about 100 feet per mile. In places where the river is located near the mountains, as at the northern end of the Sandia and west of the Caballos Mountains (Pl. VI, *B*), the gradient is 250 to 300 feet per mile.

The slopes of the western part of the Rio Grande region are much more varied than those that lie east of the river. Some are short, steep, and deeply dissected; others are many miles in length and perfectly graded, and still others, like those drained by Arroyo Salado and Rio Puerco, are but slightly inclined.

The material exposed on the corrugated slopes consists of angular rock fragments derived from the mountains. These fragments vary in coarseness with the variations in the hardness of the rock from which they were formed and with the gradient of the slopes on which they are deposited. In general, they are large near the hills and on the steep slopes and small on the lower grades and near the foot of the slopes, where they are often found intermingled with sand and pebbles that have been rounded by stream action.

TERRACES.

The long slopes terminate more or less abruptly near the river in bluffs or terraces, two of which are more or less conspicuous throughout the Rio Grande region. The highest is not continuous. It is represented west of Santa Fe by the lava-capped detrital bluffs exposed in the canyon of Santa Fe Creek, where it forms a shelf 500 feet above a lower terrace and about 800 feet above the river, as shown in the Santa Clara sheet of the United States Geological Survey. West of Albuquerque it is represented by the broad, sandy plain upon which the lava flow from Albuquerque volcanoes rests, 500 feet above the lower terrace and 800 feet above the river. (See Pl.

II, *B*, and section D–D on Pl. III.) Near the southern end of the region a similar relation occurs, the high detrital plain west of Cerro Robledo being 500 feet higher than La Mesa and 800 feet higher than the river, as shown in the Las Cruces sheet of the United States Geological Survey. The ancient surface represented by these remnants apparently had the same gradient as the Rio Grande has at the present time.

On either side of the river, at altitudes about 500 feet lower than the isolated remnants of the high terrace, are well-defined terraces, which are practically continuous from White Rock Canyon to El Paso. They are remnants of a surface that was formed principally by aggradation and later dissected by the river and its tributaries. This surface is represented at Albuquerque by the wide shelf between the lava flow and the river, shown in the foreground of Pl. II, *B*. Farther south it is represented by the Jornada and La Mesa. (See sections of Pl. III.) The surface was formed, first, by the deposition of river sand and gravel; second, by the erosion of previously deposited gravels and volcanic tuffs, illustrated in Pl. II, *A*; third, by lava flows, such as those near San Marcial (Pl. IV, *A*) and San Acacia, and, fourth, by the planation of upturned sedimentary rocks, like those exposed at the surface along the eastern base of the Caballos Mountains in the vicinity of Engle, shown in Pl. IX.

EROSION BASINS AND CANYONS.

Introductory statement.—Along the Rio Grande there are erosion basins, separated by rock canyons, as shown in Pl. I, and limited in form and size by the character of the material in which they were excavated. These basins are parts of the valley of the Rio Grande that have been broadened on account of the easy erosion of unconsolidated material while the narrower canyons were being cut in the hard rock.

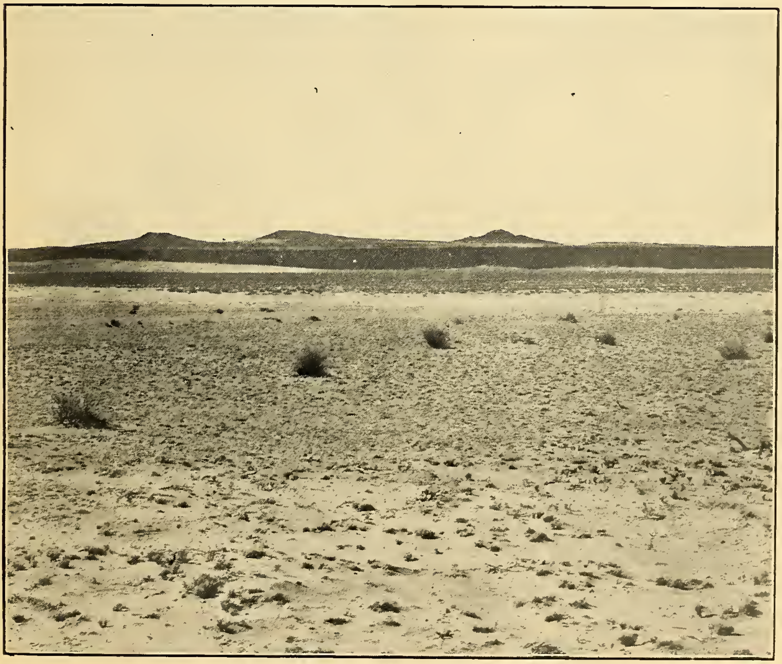
Espanola Valley.—This valley extends from the head of White Rock Canyon northward beyond the region here considered. The southern end of the valley has been described as a possible reservoir site,[a] and a contour map of it has been made. The valley is excavated in unconsolidated sand, gravel, and rhyolitic tuff. The gravel beds are exposed in bluffs several hundred feet high and are protected from erosion by the overlying igneous rock, consisting of rhyolitic tuff and basalt flows. The depth of the sands and gravels beneath the river is not known.

White Rock Canyon.—This canyon begins south of Espanola Valley, at a point where the Rio Grande enters a narrow gorge about 20 miles in length. The canyon owes its existence to sheets of hard igneous

[a] Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 4, 1899-1900.

A. FACE OF TERRACE WEST OF CABALLOS MOUNTAINS.

Showing stratified sand and gravels overlain by rhyolitic tuff.



B. ALBUQUERQUE VOLCANOES AND LAVA FLOW.

Lower terrace, 300 feet above the river, in the foreground. Lava flow, capping the detritus, 800 feet above the river.

rock, which protect the underlying sands and gravels. West of the river this rock is principally light-colored rhyolite, the color of which suggested the name White Rock Canyon, but east of the river it is basalt, of which there are two sheets, separated by a few feet of sand. The structure is indicated in a general way in fig. 2 and Pl. IV, *B*.

Near the mouth of the canyon a stream entering the Rio Grande from the east has carved a gorge, exposing about 400 feet of basalt. This gorge (Pl. IV, *B*), although comparatively small, illustrates the rugged character of the topography in the vicinity of White Rock Canyon.

Santo Domingo Valley.—This valley extends from the mouth of White Rock Canyon to a point 7 miles south of the Indian pueblo of Santo Domingo. It is 1 to 3 miles wide and contains about 13,000 acres of bottom land, which is owned mainly by the Santo Domingo Indians and has been irrigated by them for many years. The greater part of this land lies only a few feet above the bed of the river and is subject to frequent overflow.

San Felipe Canyon.—This is a short gorge separating Santo Domingo Valley from Albuquerque Valley. The canyon walls are composed of unconsolidated sand and gravel, capped by sheets of basaltic lava.

Albuquerque Valley.—This valley extends from San Felipe Canyon southward to Isleta, where it narrows on account of the basaltic lava which extends thence westward over a large part of the Sandia Mesa. The valley is about 35 miles long and 1 to 5 miles wide and comprises an estimated area of 70,000 acres of bottom land. It is terminated abruptly on either side by steep bluffs of sand and gravel forming the terraces previously described. The bluffs west of the valley consist of sand and clay, capped in places by sheets of basalt. Those to the east are composed of stratified sand overlain by coarse unstratified gravels separated from the underlying sands by erosional unconformities.

Isleta Narrows.—The constriction through which the river flows at Isleta is not properly a canyon. The broad Albuquerque Valley here narrows on account of the presence of the hard igneous rock of Isleta Volcano, an extinct volcanic cone west of the town. The lava occurs not only in the bluffs west of the river but extends nearly across the valley at the town of Isleta.

Belen Valley.—This valley, so named from the principal town within its area, extends from Isleta to San Acacia, a distance of about 45 miles, and contains an estimated area of 65,000 acres of bottom land. The Rio Puerco and the Arroyo Salado, the two largest tributaries of the Rio Grande, join the river in this valley. The Rio Puerco flows across the broad stretch of unconsolidated and horizontally bedded sand and gravel, locally known as Albuquerque Mesa.

It is a sluggish, muddy stream, practically impassable on account of quicksand, except at times of low water. The Arroyo Salado enters the valley through a canyon in the partly consolidated and upturned Tertiary strata illustrated in Pl. V, *A*.

San Acacia Gorge.—This is the narrows at the southern end of Belen Valley. The mesa east of the river near San Acacia is covered by a sheet of basalt, which originally extended farther northwestward across the present course of the Rio Grande. The river has cut thru an arm of this lava sheet, making a short narrow gorge, the walls of which, about 250 feet high, are composed of sand and gravel, protected by the cap of igneous rock.

The portion of lava left west of the river is less than one-half mile in length. West of this, and 75 feet higher than the river level, is a wide sand and gravel plain, which evidently marks the course of the Rio Grande previous to the time the river broke through the lava at the gorge. Still farther west the beds of loose sand and gravel give place to the Tertiary sediments shown in Pl. V, *B*.

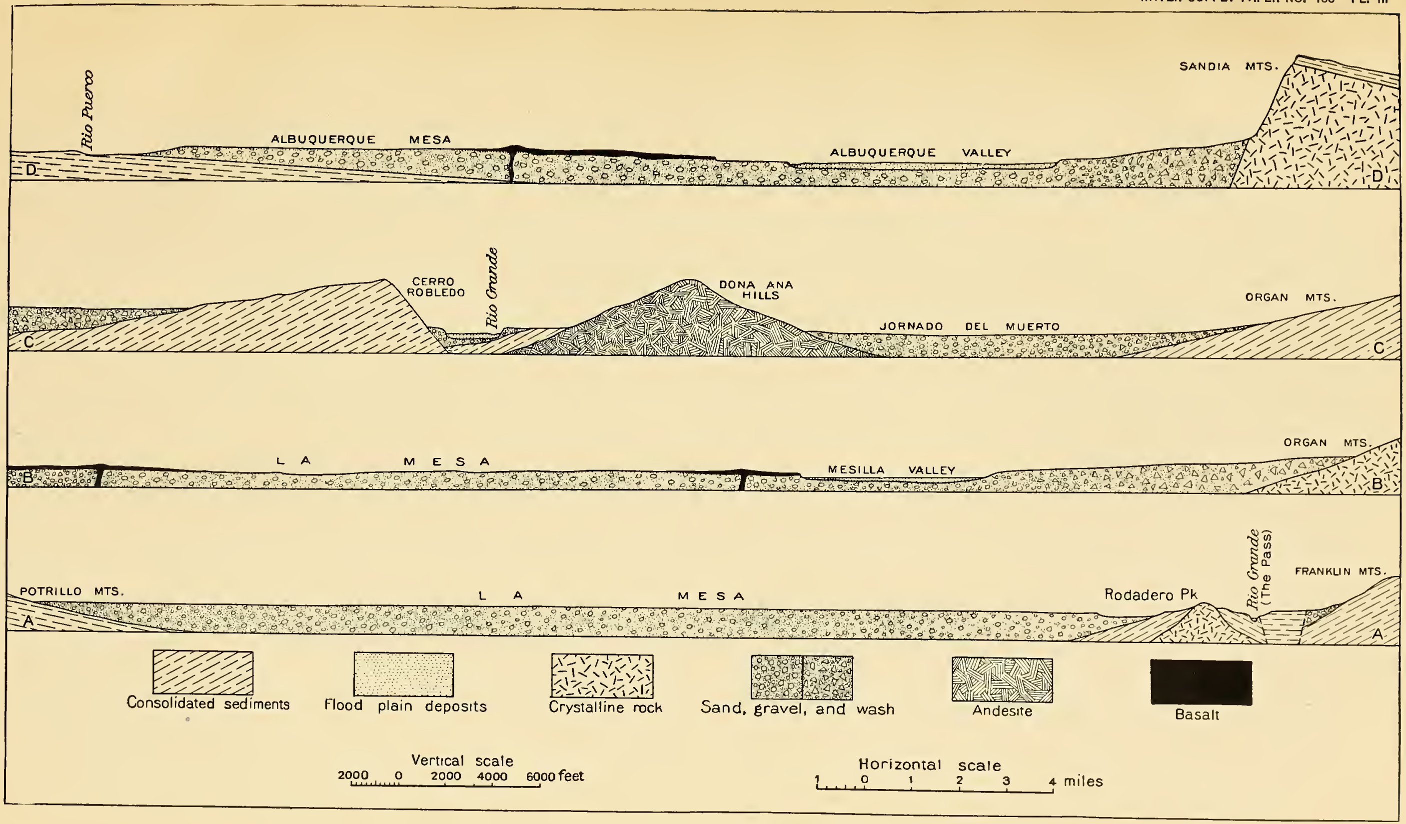
Socorro Valley.—This valley, so named from its principal town, extends from San Acacia Gorge southward to San Marcial, a distance of about 40 miles, and includes an estimated area of about 60,000 acres of bottom land. It is similar to Albuquerque and Belen valleys, except that the mountains on its sides are nearer and the corrugated detrital slopes correspondingly steeper and more eroded than those bordering the valleys previously described.

Engle Valley.—This valley extends from San Marcial to Elephant Butte, a distance of about 40 miles. This valley differs from the others described in being very narrow, as shown in Pl. I, and in its lack of bottom land. The northern half has been described and mapped as a reservoir site.[a] From this map it appears that the contour marking elevations 100 feet above the river incloses a strip of land varying in width from about 800 feet to 2 miles. The southern half of the valley is somewhat wider in places. According to the reports of the United States Reclamation Service the maximum area to be submerged in the Engle reservoir, described on pages 26–29, is about 38,400 acres, contained in a strip 40 miles long and about 1½ miles in average width.

Altho Engle Valley is cut in detritus, it is not so broad as the valleys to the north and to the south. West of the rock hills, near Elephant Butte, the detrital beds extend continuously southward (Pl. VIII) and seem to present an easy passage for the river, but it does not follow the course thus afforded.

Elephant Butte Canyon.—A few miles north of Elephant Butte the river leaves the detrital beds and enters a narrow rock canyon, which

[a] Twelfth Ann. Rept. U. S. Geol. Survey, pt. 2, p. 203.



CROSS SECTIONS OF THE RIO GRANDE REGION.

A–A, at New Mexico-Mexico boundary; B–B, near Las Cruces; C–C, at northern end of Mesilla Valley; D–D, near Albuquerque.

it occupies thence southward to the end of the Caballos Mountains. This canyon is described in detail as the Engle dam site (see pp. 26–29) and need not be further discussed in this connection.

Las Palomas Valley.—This valley, extending from Elephant Butte to Rincon, a distance of about 50 miles, is much broader than Engle Valley. The bottom lands form a part of the irrigable area, 26,000 acres in extent, under the proposed Engle reservoir. The terrace bluffs bordering this valley are especially conspicuous. West of the river they consist of well-stratified sands and gravels, but east of the valley they are more varied in both form and composition, containing not only stratified sand and gravel, but volcanic tuffs, as shown in Pl. II, *A*.

Selden Canyon.—This canyon, extending from Rincon to the head of Mesilla Valley, a distance of about 18 miles, is not so uniformly narrow as some of the other canyons. At some places, as at Penasco Rock, where a dike crosses the course of the river, the canyon is narrow. At other places it broadens to considerable dimensions. It contains about 8,000 acres of bottom land.

Mesilla Valley.—This is the largest of the erosion basins of the Rio Grande region, extending from old Fort Selden southward to The Pass, a distance of about 50 miles. It has a maximum width of 8 miles and includes about 150,000 acres of bottom land, of which 100,000 acres are irrigable. It contains the principal body of land to be irrigated from the proposed Engle reservoir, and has been surveyed in detail by the United States Reclamation Service, as shown in Pl. X. The valley is cut in the unconsolidated sand and gravel, typically exposed in the bluffs, 300 feet or more in height, bordering La Mesa on the west.

As in the Elephant Butte region, the detrital bed in which Mesilla Valley is cut extends uninterruptedly southward, west of the rock hills near El Paso; but the river, instead of following this seemingly easy course, abandoned the detrital bed and cut a canyon through the hard rock ridge at El Paso.

El Paso Canyon.—This is a rock gorge through which the Rio Grande, formerly a stream of the interior basin region of New Mexico and Mexico, past and became thenceforth a part of the Gulf drainage. The character of this canyon and its relation to the mountain ridge and the ancient course of the river—La Mesa—is indicated in section A–A of Pl. III. Rock terraces at the same altitude as the surface of La Mesa indicate that after the river had formed a graded surface over the region, principally by building up its course, it found a way across the rock ridge at The Pass. The epoch of erosion that followed was not of sufficient duration to cut more than the narrow canyon in the hard rock of The Pass, although the broad Mesilla Valley was excavated at the same time.

El Paso Valley.—This valley is similar to Mesilla Valley in being a broad basin cut in unconsolidated sand and gravel. It lies outside of the Territory of New Mexico, and is therefore not properly included in this paper, although it contains part of the land included in the Rio Grande reclamation project. The valley has been described by Richardson[a] and by Slichter.[b]

GEOLOGY.

INTRODUCTION.

No attempt is made to discuss the geology of the Rio Grande region further than is necessary to give an understanding of the physical conditions likely to affect the storage of the surface waters and the occurrence and development of the underground waters; but in order to describe these conditions some knowledge of the rocks is necessary. Three kinds of rock are recognized in this report. The first consists of granites, gneisses, and consolidated sediments, including sandstones, limestones, and shales. The second consists of unconsolidated sediments or detritus of comparatively recent origin, including river sands and gravels and mountain wash. The third comprises effusive rocks, mainly of Tertiary and Quaternary age.

ROCK FORMATIONS.

CONSOLIDATED SEDIMENTS.

The older sedimentary rocks of the Rio Grande region include strata that range in age from Algonkian to Cretaceous and that are well exposed throughout the area described. These, together with the underlying granites, form the rock basins that contain the water-bearing formations and to some extent are themselves water bearing. The consolidated sediments have special importance near Elephant Butte, where the Rio Grande cuts a sharp gorge through them at the Engle dam site, and near El Paso, at the site of the proposed International dam.

UNCONSOLIDATED SEDIMENTS.

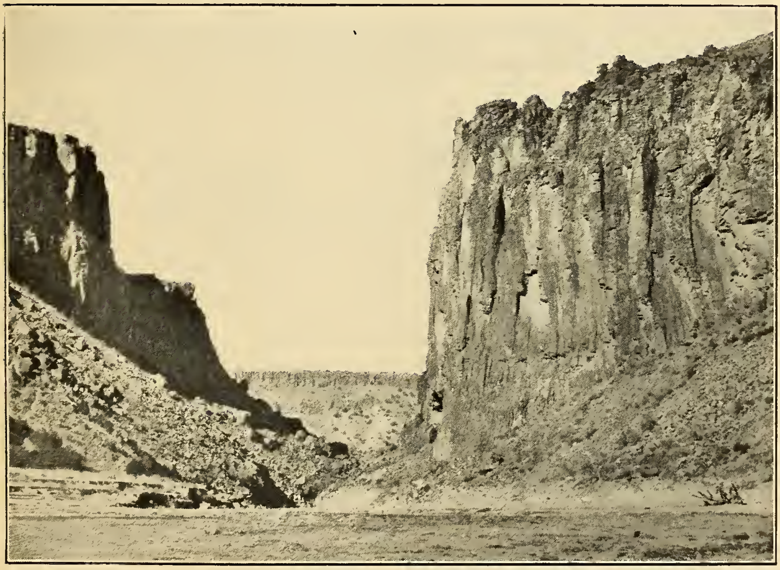
Unconsolidated material, consisting of clay, sand, and water-worn gravel, occurs generally in the lowlands along the river, in the terraces on either side of the Rio Grande Valley, in the central part of the Jornada del Muerto, and in La Mesa, west of Mesilla Valley. The slopes lying between the river and the mountains consist largely of angular rock débris, derived as wash from the mountains.

The older detrital beds are partly cemented, but the younger ones are wholly unconsolidated and allow water to pass freely through them.

[a] Richardson, G. B., Reconnaissance in trans-Pecos Texas: Bull. Univ. Texas No. 23, 1904, pp. 95–108.
[b] Slichter Charles S., Observations on the ground waters of the Rio Grande Valley: Water-Sup. and Irr. Paper No. 141, U. S. Geol. Survey, 1905, pp. 9–51.

A. LAVA-CAPPED MESA AT SAN MARCIAL.

The sheet of basalt resting upon the sand and gravel is the edge of the great flow covering the north end of the Jornada del Muerto.



B. SIDE GORGE AT THE ENTRANCE TO WHITE ROCK CANYON, NEAR ESPANOLA DAM SITE.

Showing columnar basalt in the foreground, and the rhyolite west of the river in the background.

The detritus has a great, though unknown thickness. A well at Santa Fe penetrates it nearly 1,000 feet; another at Sandia, N. Mex., 893 feet; one at Lanark, west of Mesilla Valley, 945 feet; and one in a neighboring basin,[a] near El Paso, 2,285 feet, but in none of these wells has bed rock been reached. Where the older and partly cemented beds have been upturned and exposed to view in Arroyo Salado, they have an observed thickness of several thousand feet. Their character is indicated in Pl. V, *A*, *B*. The younger or uncemented sands and gravels are well exposed in the terraces on either side of the river.

IGNEOUS ROCKS.

The igneous formations that are important in a discussion of the water supply are principally of Tertiary and Quaternary age, and occur in the form of massive flows, beds of tuff, volcanic necks, dikes and sheets, and crater cones. The older effusive masses, consisting of andesites, rhyolites, and other rocks closely related to these, occur in more or less isolated masses at many places throughout the Rio Grande region and are perhaps best represented by the thick beds of tuff on the eastern slope of the Jemes Mountains in the northern part of the Rio Grande region, by the Socorro Mountains and Cerro Magdalen in the central part, and by the Dona Ana Hills in the southern part. Their formation antedates the accumulation of at least the upper part of the detritus as fragments of the rock are contained in the detrital beds.

The younger igneous rocks consist of dark-colored basalts, occurring mainly in sheets capping the detritus and in crater cones which retain their original form in great perfection, as shown in Pl. VI, *A*. Basaltic rock also occurs in dikes and volcanic necks penetrating the older rocks. Among the more conspicuous sheets capping the detritus may be mentioned those west of Santa Fe, through which the river has eroded White Rock Canyon, those covering parts of the mesa west of Albuquerque (see Pl. II, *B*), the San Marcial flow (see Pl. IV, *A*,) and the basalt flows of La Mesa west of Mesilla Valley. The dikes and volcanic necks become important in the vicinity of the Engle reservoir (Pl. IX), where they will probably supply building stone for the proposed dam.

STRUCTURE.

GENERAL CHARACTERISTICS.

The geologic structure of the Rio Grande region is complicated, and much detailed investigation is necessary before it can be adequately described. The main structural features, however, are known in a general way. Great synclines, such as the Jornada del Muerto, occur,

[a] Richardson, G. B., Reconnaissance in trans-Pecos Texas: Bull. Univ. Texas No. 23, 1904, p. 96.

and monoclinal mountains, formed by faulting and the tilting of crust blocks. The rocks thus flexed and faulted are mainly of pre-Tertiary age, but the Tertiary beds are strongly upturned in places, indicating that some crustal movement took place after these beds were formed. (Pl. V, *A*). The older valleys of erosion and the troughs formed by the tilted blocks have been partly filled with unconsolidated detritus consisting of sands, waterworn gravels, and angular mountain wash.

EASTERN BORDER.

The eastern part of the Rio Grande region is occupied by the Rocky Mountain uplift, which extends through central New Mexico. The southern end of the Rocky Mountains, terminated at the south by Glorieta Pass, is a granitic mass upon which lie strata that dip away from it to the east, south, and west. But south of this pass the underlying granite is covered, more or less completely, with sedimentary rocks dipping in various directions. The strata of Glorieta Mesa incline toward the south, and those of the Sandia Mountains, the Manzano Range, and Sierra Oscura toward the east. The strata of Chupadera Mesa are nearly horizontal, while those of the San Andreas Range and the Organ and Franklin mountains dip toward the west. Numerous faults occur, with displacements measured in hundreds of feet and several with displacements of thousands of feet.

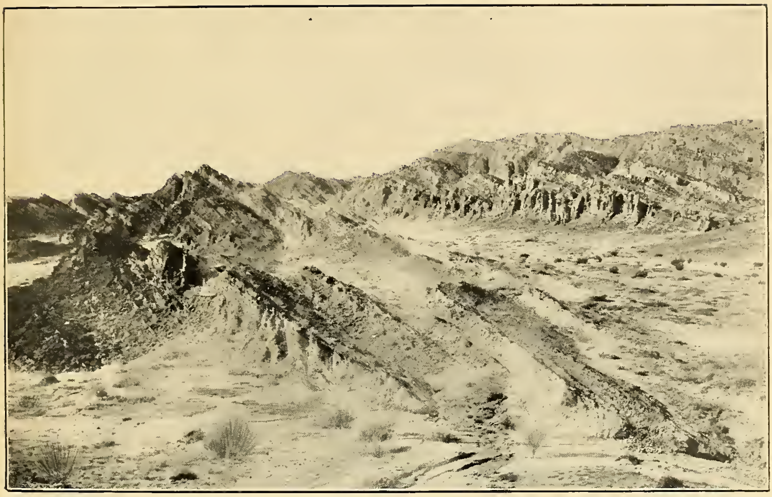
WESTERN BORDER.

The western part of the Rio Grande region is less mountainous than the eastern part, and a greater proportion of it is covered with detritus, which obscures the structure to a large extent. In the Rio Puerco Valley strata dip to the east and are believed to pass beneath the Rio Grande Valley, while strata of the same geologic age occur in the Sandia Mountains, several thousand feet above the Rio Grande Valley, the difference in elevation being due to faulting along the western face of the Sandia Mountains and the eastward tilting of the Sandia block, as indicated in section D–D of Pl. III. On the other hand, the crust block forming Sierra Ladron, a few miles south of Rio Puerco, has been tilted steeply to the west.

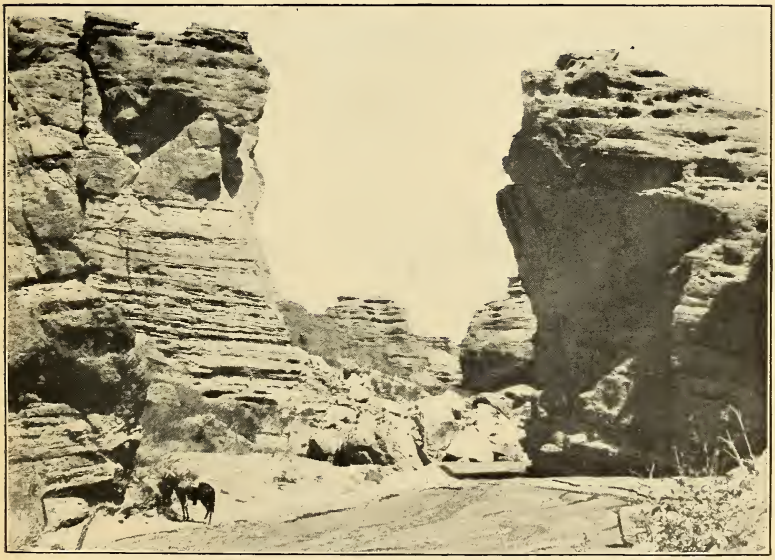
In the western part of the region many of the mountain groups, such as Jemes and Socorro mountains and Cerro Magdalen, are composed principally of effusive rock.

CENTRAL AREA.

The structure of the Rio Grande region is best shown in the central portions, where the river has removed the detritus in many places, exposing the consolidated rocks. The Caballos and Fra Cristobal ranges, forming the western limb of the Jornada syncline, are cut off



A. TERTIARY STRATA IN ARROYO SALADO AT THE BASE OF SIERRA LADRON.



B. CANYON IN TERTIARY SEDIMENTS WEST OF SAN ACACIA, N. MEX.

abruptly on the west by great faults which are plainly exposed and traceable for longd istances. (See Pl. VII.) Cerro Robledo furnishes a characteristic type of structure. (See Pl. III.) East of the river Carboniferous limestone, dipping westward, passes beneath the Rio Grande Valley. The same limestone occurs in the hills to the west 2,000 feet above the river, the difference in altitude being due to faulting and the tilting of the Cerro Robledo block.

Displacements by faults much greater than that at Cerro Robledo are evident at a number of places. The western face of the Caballos Mountains (see Pl. VI, *B*) and the Fra Cristobal Mountains (Pl. VII) are fault scarps, and Cerro Cuchillo is an excellent example of a tilted block. With the exception of the Jornada del Muerto, the Rio Grande region may be properly said to consist of a series of block mountains with troughlike depressions intervening between them.

TOPOGRAPHIC DEVELOPMENT.

EROSION.

Altho the elevations and depressions constituting the Rio Grande region are due principally to crustal deformation, the topography has been more or less modified by erosion and deposition. Many of the mountain slopes are precipitous and show little modification by erosion, as illustrated in the Caballos Mountains. (Pl. VI, *B*.) Other slopes are comparatively mature. Along the eastern base of the Caballos and Fra Cristobal ranges, particularly in the vicinity of Engle, the stratified rocks dipping eastward beneath the Jornada have been practically base-leveled over a considerable area. Whether the base-level extends beneath the Jornada generally, as stated by Keyes,[a] or is local, can only be conjectured at the present time, as the older rocks within the syncline are exposed over a comparatively limited area, being for the most part buried to unknown depths by detritus.

SEDIMENTATION.

Tertiary.—The older portions of the detritus contained in the rock basins consist of well-stratified beds of sand, gravel, and mountain wash, more or less faulted in places and otherwise disturbed by crustal movements. They are undoubtedly of Tertiary age. In other places sediments, apparently of Tertiary age, are not separable at present from the younger or Quaternary deposits.

Quaternary.—The unconsolidated sands, gravels, and "wash" covering the greater part of the Rio Grande region is of Quaternary age and occurs in at least two distinctly separable formations. The more extensive one, locally known as the mesa gravels, occurs in the terraces along the river and forms the corrugated slopes lying between

[a] Keyes, C. R., Water-Sup. and Irr. Paper No. 123, U. S. Geol. Survey, 1905, p. 25.

the river and the bordering mountains. The second occurs in the flood plains in all of the erosion basins previously described. In the Jornada del Muerto and La Mesa the sand and gravel beds belonging to this formation are not dissected by erosion, but lie practically as they were deposited, at an altitude 300 to 350 feet above the present bed of the river.

The mesa gravels originally filled the basins to altitudes represented by the terraces, and in them the erosion basins were cut. The depth to which these were excavated and later filled is not definitely known, but the general relations of the various gravel beds to each other and to the rock basins containing them are illustrated in fig. 1.

TERTIARY AND QUATERNARY HISTORY.

SURFACE DEFORMATION AND FIRST VOLCANIC ERUPTION.

The crustal movements that produced the structural and geographic features described began at the commencement of or sometime during the Tertiary period with the formation of monoclinal mountains and troughlike intermontane valleys. About the same

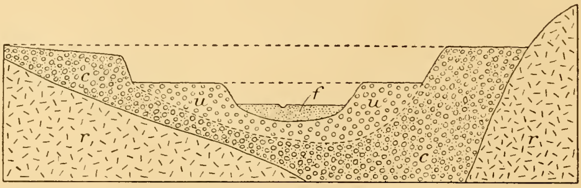


Fig. 1.—Sketch section illustrating the detrital deposits of Rio Grande Valley. *r*, Rock basin; *c*, detritus of the higher terrace; *u*, detritus of the lower terrace; *f*, flood-plain deposits.

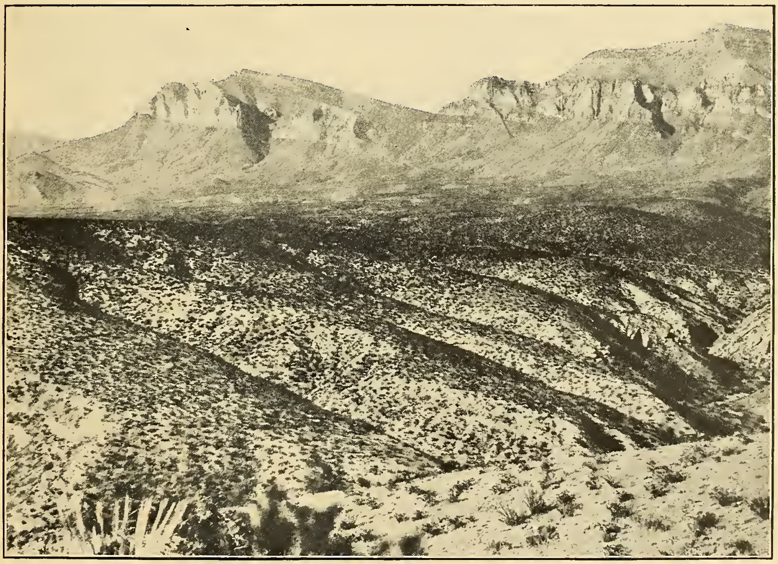
time great masses of andesite and rhyolite were extruded, remnants of which are now found in the Jemes Mountains, the Socorro Mountains, the Dona Ana Hills, and elsewhere. This deformation and volcanic activity evidently occurred late in the Tertiary period, as Tertiary strata are upturned and in places intersected by rhyolite.

FIRST ACCUMULATION OF GRAVELS.

The structural troughs between the tilted mountain blocks formed natural lodgment areas for sediment. It can not be stated at present whether the sediments are partly of lacrustrine origin or wholly subaerial, nor is their maximum thickness known, but well records indicate a thickness of thousands of feet. The material exposed in the terraces and penetrated by the shallow wells, consisting mainly of coarse sand and gravel, is presumably of river origin, but some of the deep wells penetrate thick beds of sandy clay, possibly of lacustrine accumulation. The surface of this first gravel accumulation is preserved in a number of places, where it forms the upper terrace, 800 feet above the river, described on page 11.

A. SANDIA VOLCANO, WEST OF ISLETA, N. MEX.

A volcanic cone of recent origin, composed of basaltic cinders.



B. CABALLOS MOUNTAINS.

Showing the western escarpment and the corrugated alluvial slope at its base.

SECOND VOLCANIC ERUPTION.

After the depressions had been filled to altitudes represented by the upper terrace, extensive sheets of basalt were outpoured over the sands and gravels. In the lava fields west of Santa Fe, and in those near Bernalillo, two sheets of basalt occur, separated by a few feet of gravel, as shown in fig. 2. West of Albuquerque (Pl. II, *B*), and also in the extensive lava fields west of Isleta, the older sheets apparently belong to this epoch of eruption, and it is probable that many of the older masses of basalt in other parts of the Rio Grande region were extruded at about the same time.

FIRST EPOCH OF EROSION.

The second volcanic eruption was apparently accompanied by some change, possibly climatic, which caused the Rio Grande to erode its channel. During this epoch the river probably flowed through the Jornada del Muerto south of San Marcial, across La Mesa west of El Paso, and southward into the basin region of northern Mexico, eroding a valley 10 to 20 miles wide.

Ancient course of the Rio Grande.—Many facts point to the inference that the ancient course of the Rio Grande was not the same as its present course south of San Marcial. Some of the data leading to this inference have been given and others will be presented in the following paragraphs. Briefly stated, the facts are these:

The Jornada and La Mesa have the geographic position, form, surface elevation, and gradient that would be expected in a débris-filled valley; they contain unconsolidated sands and gravels as deep as wells have penetrated; their surface elevations and gradients indicate that they are parts of a graded surface that formerly extended throughout the Rio Grande region and is now represented north of San Marcial by the low terrace previously described, this ancient surface having the same gradient as that of the river at the present time.

At the point where the river leaves this old valley the surface is covered by an extensive basalt flow (the San Marcial lava sheet, covering about 160 square miles) resting on sand and gravel beds. The lava is not eroded at the surface and is covered only by wind-blown sand. Large quantities of loose shifting sand lie immediately north of the lava beds.

Engle and Las Palomas valleys are much narrower than the other erosion basins, and are cut in detritus which contains gypsum in places. The beds are cemented to some extent, and are associated with rhyolite, presumably much older than the basalt and its underlying detritus at San Marcial.

The measure of consolidation, presumably due to difference in age, is indicated in the size of the erosion basins. While the river cut canyons in hard rock it excavated narrow valleys in the cemented detritus west of Caballos and Fra Cristobal mountains and broad basins like Socorro and Mesilla valleys in the unconsolidated detritus to the north and south.

From these facts the inference is drawn that the ancient Rio Grande flowed through the Jornada and La Mesa into the interior basin of Mexico, and that in comparatively recent geologic time changes occurred which turned it out of its valley and away from the interior basin toward the Gulf of Mexico.

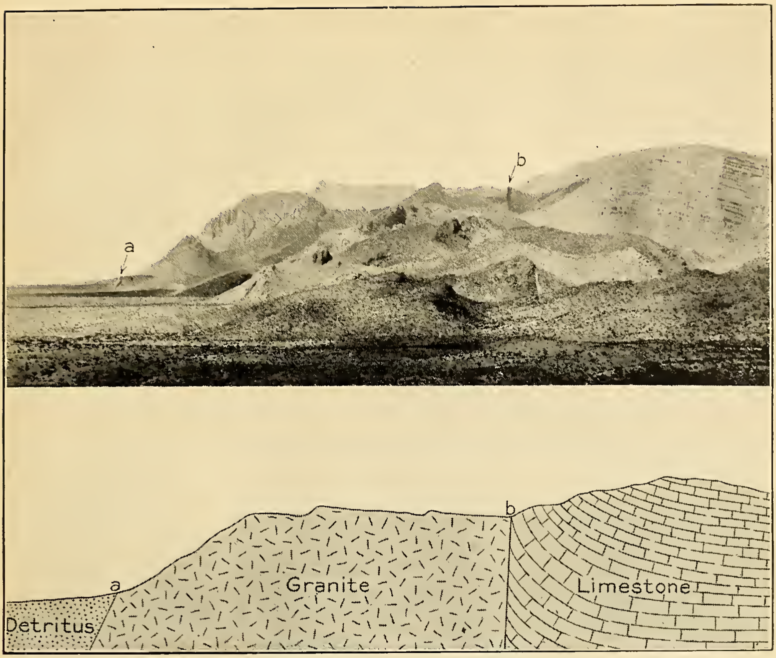
SECOND ACCUMULATION OF GRAVELS.

During the second epoch of deposition the river filled its valley with sand and gravel to the grade represented by the lower terrace (*uu* of fig. 1) and by the surface of La Mesa and the Jornada del Muerto. In La Mesa the ancient valley is about 20 miles wide and the filling is mainly fine sand near the surface and somewhat coarser sand and gravel beneath. In the Jornada del Muerto the filled valley is narrower and the material is coarser, many of the pebbles having a diameter of several inches. In Albuquerque Valley the quantity of filling during this epoch is much less than in La Mesa and the Jornada, and is best represented by the coarse gravel deposits of the bluffs near Albuquerque. Still farther north, in Santo Domingo Valley, near the northern end of the Rio Grande region, the deposits are very limited, and the river here was apparently employed mainly in broadening its valley.

The graded surface formed by the river during this epoch was one mainly of erosion in Santo Domingo Valley, where a broad shelf was cut 500 feet below the surface of the older gravels; one formed partly by erosion and partly by deposition in Albuquerque Valley; and one mainly of deposition in the Jornada and La Mesa. Throughout the Rio Grande region this surface, represented now by the terraced bluffs, is about 300 feet above the river, except where it has been cut down by later erosion.

THIRD VOLCANIC ERUPTION.

Near the close of the second period of sedimentation extensive volcanic disturbances occurred throughout the Rio Grande region, resulting again in the outpouring of great sheets of basalt. The most conspicuous of these are near San Marcial (Pl. IV, *A*) and on La Mesa west of Mesilla Valley. The San Marcial flow, covering about 160 square miles, was outpoured on the Jornada del Muerto, then occupied by the Rio Grande, and probably created a dam that formed a temporary lake in which were accumulated the great quantities of sand found on the Jornada north of the lava sheet.



A. WESTERN FACE OF THE FRA CRISTOBAL MOUNTAINS.

Showing two faults, a and b.

B. FAULT PLANE AT THE WESTERN BASE OF FRA CRISTOBAL MOUNTAINS.

Showing near view of a, above.

DIVERSION OF THE RIO GRANDE.

There is no evidence that the river ever flowed over the San Marcial lava sheet. The surface of this sheet is not eroded and, so far as observed, is devoid of foreign matter except a small amount of wind-blown sand. The volcanic dam, aided possibly by surface movements accompanying the volcanic eruptions, evidently diverted the river from its old valley in the Jornada to a new course for a distance of about 100 miles west of the Caballos and Fra Cristobal mountains. At Dona Ana it returned to the old débris-filled valley, which it crossed diagonally and abandoned again at El Paso.

Several phenomena which otherwise are difficult to explain are made clear by a recognition of this change in the course of the river.

First, as previously stated, the surface of the Jornada between San Marcial and Mesilla Valley has an average gradient of 4.5 feet per mile, which is practically the gradient of the river at the present time.

Second, the detrital beds cut by the river west of the Fra Cristobal and Caballos mountains are associated with rhyolite, apparently extruded at the same time as the rhyolites previously described as of Tertiary age, indicating that the detritus is older and probably more difficult to erode than the loose sands and gravels that were deposited later.

Third, near Rincon, and again in Selden Canyon, gypsum was noted in the detrital beds, but nowhere was any indication of gypsum found in the mesa gravels referable to the epoch in which the Jornada and La Mesa were filled.

Fourth, as previously stated, Engle Valley is much narrower than the other erosion basins formed at the same time—as, for example, Mesilla and Belen valleys, which have been excavated from river sands and gravels known to be of recent origin. This difference is due, no doubt, to the greater resistance to erosion of the older detritus.

SECOND EPOCH OF EROSION.

The volcanic eruptions and the change in the course of the river were followed by a second epoch of erosion. In again eroding a valley, the river worked principally in the unconsolidated sands and gravels previously deposited, excavating the erosion basins, but at a number of places where it had wandered from its old course it cut its channel in hard rock, forming the various canyons. The result is the succession of comparatively broad basins and short rock canyons that characterize the Rio Grande region.

ACCUMULATION OF SILT.

The second epoch of erosion was followed by the deposition of the silt and sand that now form the flood plains of the erosion basins. The depth of this third valley filling is not great. Borings indicate a maximum depth of 85 feet at the International dam site in El Paso Canyon and of 72 feet at the Engle dam site, near Elephant Butte. The depth within the basins probably does not differ greatly from that in the canyons, but this can not be stated positively.

The well records given in the section on underground waters indicate that the mesa gravels (*uu* of fig. 1) are probably encountered at depths of 30 to 80 feet. The first "cemented sand" in the Albuquerque well (p. 34) is presumably a hardened layer of the Tertiary beds, and the gravel beds in the Mesilla Valley wells (pp. 41-46), encountered at depths of 30 to 75 feet, are interpreted as belonging to the mesa gravels. The depth of flood-plain deposit thus indicated corresponds well with the known depth of filling in the canyons.

The deposition of sand and silt in the erosion basins causes frequent changes in the course of the river, so that bayous, sloughs, and oxbow lakes are common in the bottom lands. This is well illustrated in Mesilla Valley (Pl. X), where many abandoned courses occur, particularly near the southern end, some still occupied by streams and others nearly filled with silt. A characteristic change in the channel of the river occurred in 1905 near the head-gate of Las Cruces canal, at the northern end of Mesilla Valley. During the spring floods of that year the river broke through the narrow neck of land on the western side of the valley, leaving the head-gates about a mile from the new channel.

B. M. Hall, supervising engineer of the United States Reclamation Service, in charge of the Rio Grande project, has made computations of the amount of silt carried by the Rio Grande. He arrives at the conclusion that the river carries, on the average, 14,580 acre-feet of mud a year, or enough when dry to cover 14,580 acres 1 foot deep. The computation, although made for the purpose of estimating the time required to fill the reservoirs with mud, is useful in this connection in indicating the possibilities of rapid accumulation wherever opportunity is offered.

During times of flood the river naturally carries its maximum amount of silt, which is thus admitted to the sloughs and overflow districts and gradually fills them to the common level of the flood plain. A similar action takes place in the irrigation ditches, which rapidly fill with silt. Some of the older ditches have thus been built up many feet above the level at which they were originally constructed.

RESERVOIR SITES.

INTRODUCTORY STATEMENT.

The alternation of erosion basins and rock canyons in the Rio Grande Valley is especially favorable for the construction of reservoirs and the conservation and use of the flood waters of the river. Available dam sites occur in the canyons, while the broad basins are suitable for storage reservoirs or for irrigation, according to location and character. Several reservoir sites have been selected and the two most promising ones—the International reservoir, at the southern end of the region, and the Engle reservoir, west of the Fra Cristobal Mountains—have been investigated in detail.

INTERNATIONAL RESERVOIR.

The proposed International reservoir is located at the southern end of Mesilla Valley and was designed by its promoters to store water to be used in El Paso Valley, which lies partly in Texas and partly in Mexico. The dam site is in the canyon about 4 miles north of the city of El Paso.

El Paso Canyon is a narrow gorge carved in solid rock, consisting of Lower Cretaceous sediments and eruptive rocks. The strata have been considerably fractured and faulted. Rodadero Peak, to the west, has a granitic core overlain by highly inclined Lower Cretaceous sandstones, shales, and limestones. East of the river the strata lie more nearly horizontal, while in the Franklin Mountains, still farther to the east, strata older than Cretaceous dip steeply to the west. The shattered and faulted state of the rock is apparently the only geologic condition unfavorable to El Paso Canyon as a good dam site. The gorge is narrow, the rock abutments are firm, and the depth to bed rock in the channel is not prohibitive, as it is found at a maximum depth of little more than 80 feet. The site has been described in detail in the report of the International (Water) Boundary Commission.[a]

Although the dam site of the proposed reservoir is a good one, geologic conditions are not favorable to the successful storage of water in the southern part of Mesilla Valley. As previously pointed out, the old gravel-filled valley of the Rio Grande passes southward into Mexico west of Rodadero Peak. The water of the reservoir would be impounded in the basin eroded from the unconsolidated gravels of the old valley fillings and would undoubtedly escape to some extent through these gravels until such time as they might become impervious from silting. It is an open question how much time would elapse before this silting would become effective in preventing leakage.

[a]Proceedings International (Water) Boundary Commission, United States and Mexico, 1903, vols. 1 and 2.

ENGLE RESERVOIR.

LOCATION.

The proposed Engle reservoir site is located in Engle Valley, west of the Fra Cristobal Mountains, and is best reached from Engle, a small town on the Atchison, Topeka and Santa Fe Railway. The site of the proposed dam is in the rock canyon near Elephant Butte, a large volcanic neck standing near the river, as shown in Pl. IX.

ROCK FORMATIONS.

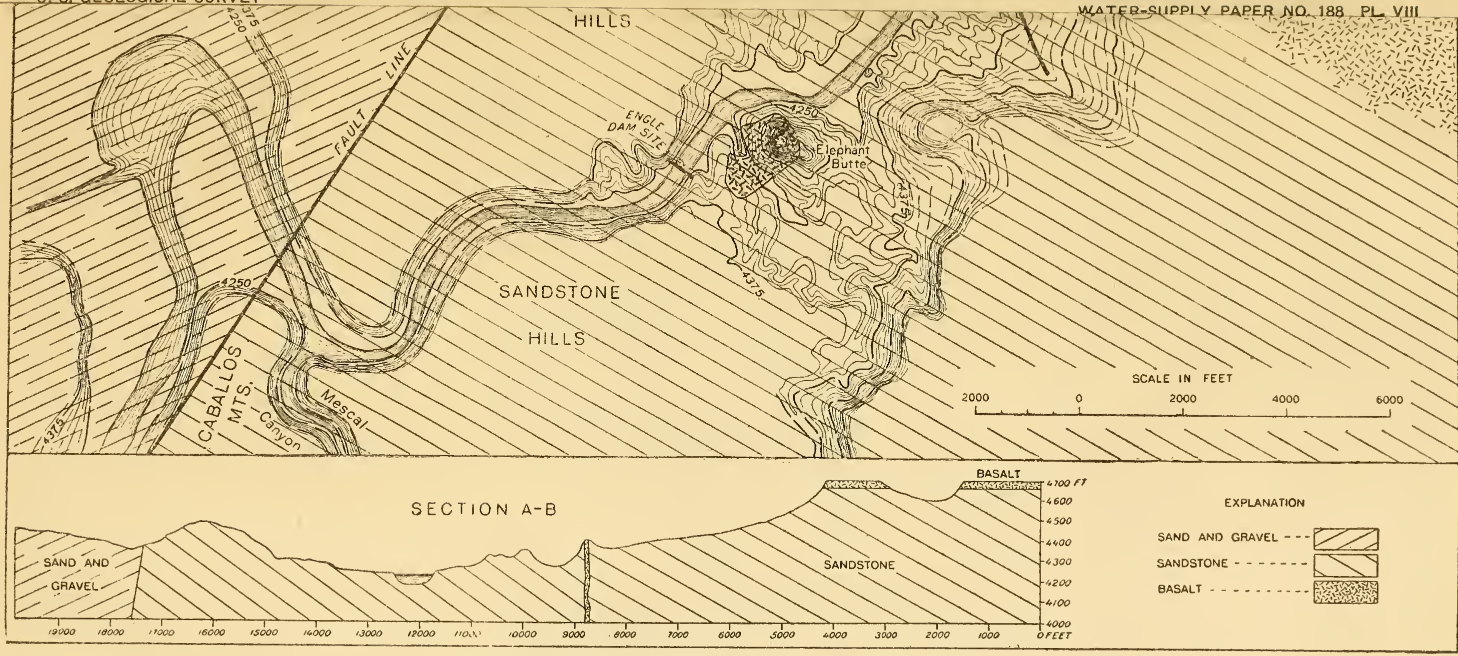
The rocks near the proposed reservoir are of several kinds. In the mountains, a few miles distant, there are pre-Cambrian granites overlain by Paleozoic and Mesozoic sandstones, shales, and limestones, and in the valleys there are Tertiary and Quaternary sands, gravels, and eruptive rocks. The rocks that will probably be of economic importance in building the proposed dam are the Carboniferous limestones and shales of the Caballos Mountains, the Cretaceous sandstones forming the abutments of the dam and comprising the greater part of the area mapped in Pl. VIII as "rock," also shown in the foreground of Pl. IX, and the basaltic rock found in Elephant Butte and in the dikes of that vicinity, as well as in the lava flows and crater cones on the Jornada to the east, shown in the distance in Pl. IX.

The unconsolidated sands and gravels of Tertiary and Quaternary age are mainly of negative importance, since they form the floor and confining walls of the reservoir and endanger leakage.

STRUCTURE.

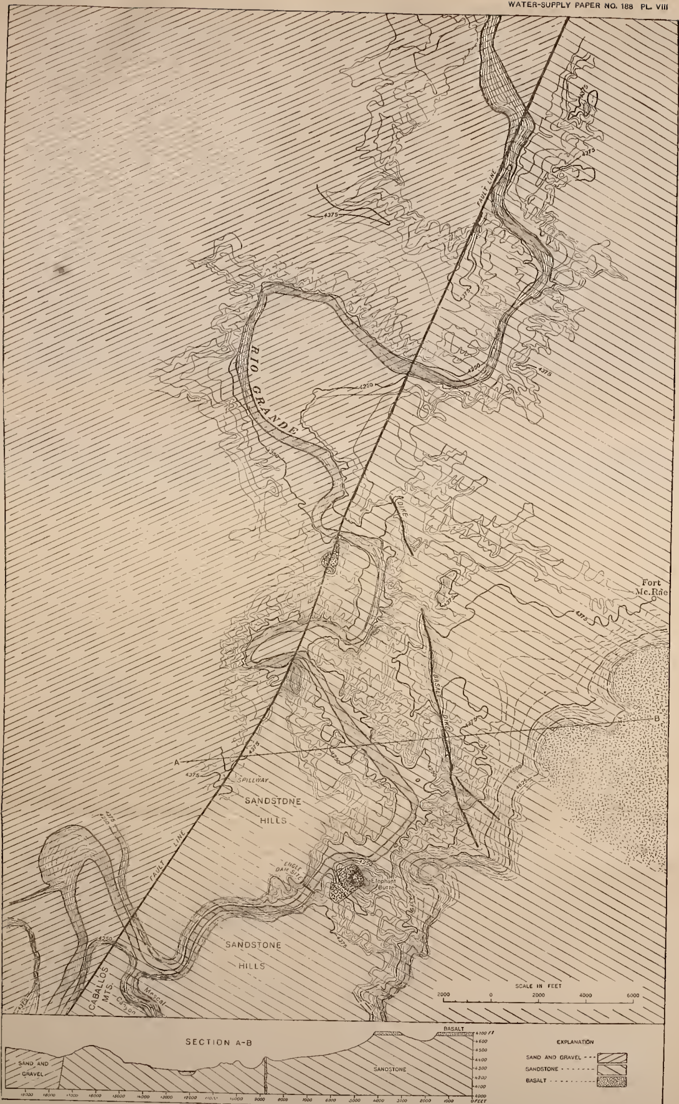
The geologic structure in the vicinity of Elephant Butte has been described in a general way under the heading "Central area" (pp. 9–16), where it is shown that the face of the Fra Cristobal and Caballos mountain ranges (see Pl. VII) are due to faulting and that the detrital valleys are due to the filling of the troughs thus formed with rock débris. The structure is illustrated in detail in the Elephant Butte area, a map and cross section of which are given in Pl. VIII. The fault at the western base of the mountains passes through this region, separating the unconsolidated detrital beds to the west from the rock formations to the east. The rocks, consisting mainly of Upper Cretaceous sandstones and shales, are more or less fractured near the fault and incline in a general easterly direction, the dip varying from about 10° to 90°.

The high lava-covered surface, shown at the right in the section Pl. VIII and in the distance in Pl. IX, is the western edge of the Jornada del Muerto. About 300 feet below this level and 150 feet above the river a broad terrace is cut in the sandstones east of the fault line and in



GEOLOGIC MAP OF ELEPHANT BUTTE REGION.

Showing the areal distribution of the rocks, the fault line between consolidated rock and detritus, and the superimposed course of the Rio Grande.



GEOLOGIC MAP OF ELEPHANT BUTTE REGION.

Showing the areal distribution of the rocks, the fault line between consolidated rock and detritus, and the superimposed course of the Rio Grande.

the detrital beds west of the fault. This terrace is traceable throughout the length of Engle and Las Palomas valleys and is most conspicuous west of the river, where it forms a shelf several miles wide in places. It differs from the terraces illustrated in fig. 1 in being a surface mainly of erosion, probably formed at a time when the down cutting of the river was temporarily arrested, for some reason as yet unknown, during which time the river cut laterally, flowing in part over the rock and in part over the detrital beds to the west, crossing and recrossing the fault line. When the river resumed its down cutting it eroded a canyon partly in rock and partly in detritus, as shown in Pl. VIII, instead of taking the course to the west, where no hard rock would have been encountered.

SPILLWAY.

The ease with which erosion is accomplished in the detrital beds is well illustrated in the three oxbows formed west of the fault line, where the river passes from the rock into the detritus. The southern and middle bows are now only 2 miles apart and are separated by a ridge of detrital material already partly eroded away. The spillway of the Engle reservoir has been located tentatively in this depression. Considered from the topography alone the depression is an excellent location for a spillway, since the waters from the overflowing reservoir would escape at a point far enough away from the dam to insure the safety of that structure. The nature of the rock, however, must also be considered.

A small valley heading in the spillway at the summit of this ridge is indicated in Pl. VIII. The map was not completed to the south but a similar valley extends from the spillway southward to the bend in the river at the northern end of the Caballos Mountains. These valleys have been carved from the unconsolidated sediments by such temporary streams as result from the drainage of a very small area, a fact distinctly unfavorable to the location of the spillway of a great reservoir in material so easily eroded.

The proposed spillway is close to the fault line and it is possible that solid rock might be found at no great depth beneath the surface. In a small valley south of the spillway sandstones occur in a nearly vertical position. But whether these are near enough to the surface to warrant the establishment of a spillway at the point proposed remains to be determined.

A spillway constructed near the dam might have the disadvantage of greater cost, since it would require the excavation of a considerable amount of hard rock, but the advantage of greater durability and the absence of danger from rapid erosion along the course of the overflowing waters would probably more than compensate the additional cost.

CONSTRUCTIONAL MATERIALS.

Building stone.—Several varieties of building stone are found within the Elephant Butte area. Massive limestones and red sandstones of Carboniferous age occur in the Caballos Mountains, the northern end of which is 1½ miles distant from the site of the proposed dam. Massive sandstones of Upper Cretaceous age occur at the dam site in the walls of the canyon. Field observations indicate that these will probably prove valuable for purposes of construction. But the strongest and most durable as well as the most accessible building stone is the basalt of Elephant Butte, which occurs close to the dam site. (Pl. VIII.)

Cement material.—The problem of procuring cement for the construction of the dam is important. Cement must either be hauled about 12 miles from the nearest railway station or manufactured near the dam site. Cement material is available in the Elephant Butte area. In the northern end of the Caballos Mountains, at the mouth of Mescal Canyon, limestone and shale occur in abundance. Samples of each were taken and were analyzed in the laboratory of the United States Reclamation Service at Berkeley, Cal. The samples were not selected by one familiar with the technical requirements of cement manufacture, and probably more suitable material may be found. The analyses of these samples, given below, must be regarded as preliminary, but indicate that good cement materials may be found near the dam site.

Analysis of limestone from the northern end of Caballos Mountains.

[C. H. Stone, analyst.]

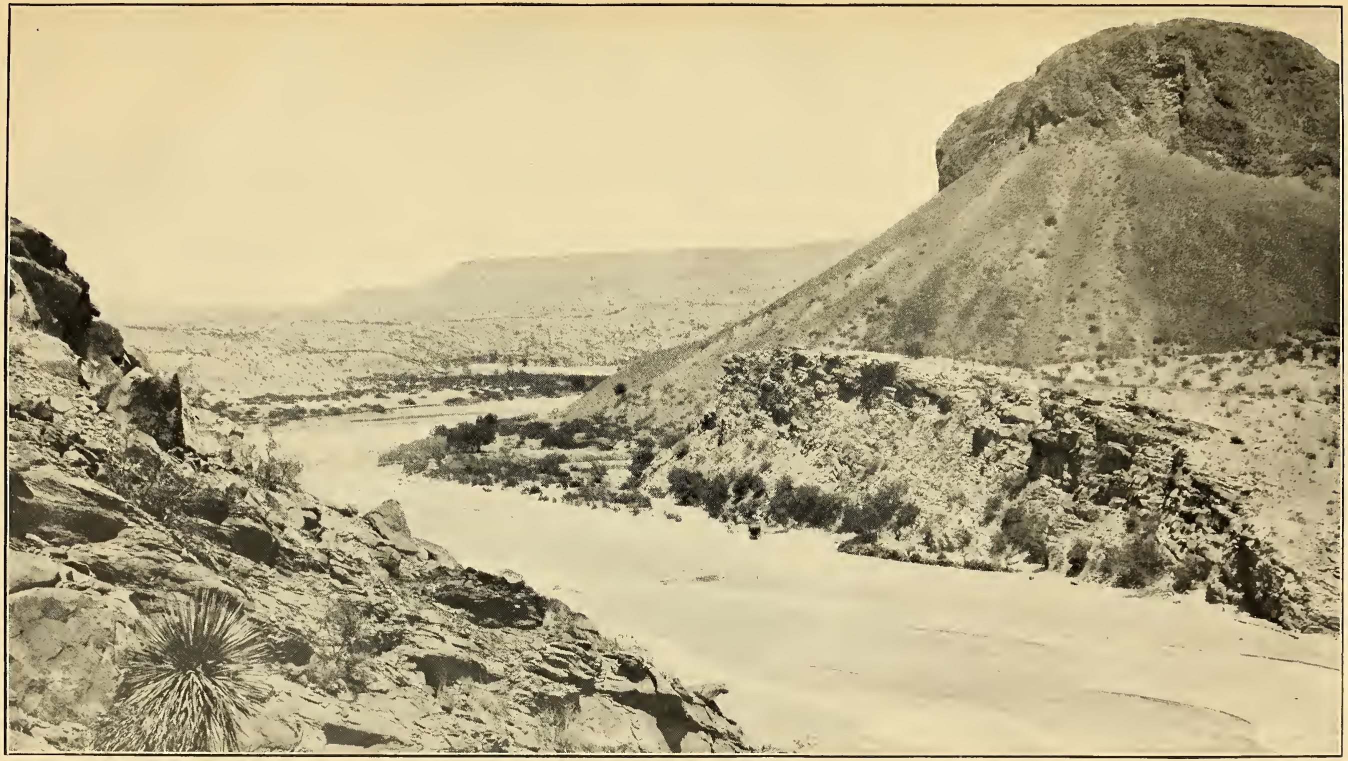
Silica (SiO_2) and insoluble matter	7.94	Soda (Na_2O)	0.28
Alumina (Al_2O_3) and ferric oxide (Fe_2O_3)	0.80	Sulfur trioxide (SO_3)	0.30
Lime (CaO)	44.99	Carbon dioxide (CO_2) calculated to combine with CaO	39.29
Magnesia (MgO)	1.23		95.30
Copper oxide (CuO)	0.38	Moisture	0.11
Potassa (K_2O)	0.09		

Analysis of shale from the northern end of Caballos Mountains.

Silica (SiO_2)	63.74	Soda (Na_2O)	Undet.
Ferric oxide (Fe_2O_3)	6.44	Potassa (K_2O)	Undet.
Alumina (Al_2O_3)	17.33	Sulfuric trioxide (SO_3)	Trace.
Lime (CaO)	5.51	Ignition loss (H_2O, CO_2)	
Magnesia (MgO)	1.86		94.88

RATIONAL ANALYSIS.

Clay substance	27.20
Quartz	3.25
Feldspathic detritus	69.55



ENGLE DAM SITE.

Showing Elephant Butte at the right, the edge of the Jornada del Muerto in the distance, the tilted Cretaceous sandstones in the foreground, and the dry bed of the Rio Grande.

The ratio $\frac{SiO_2}{Fe_2O_3+Al_2O_3}=2.6$ is well within the limits of the ratio >2.3 or <3.6. The MgO content is low, and the absence of SO_3 makes this material one of the purer clays, considered from a technical point of view.

Coal.—Coal has been found in Mescal Canyon about 4 miles south of Elephant Butte. Where exposed at the surface the beds are only a few inches thick, but are associated with a considerable amount of carbonaceous shale. The coal is in the same formation that contains valuable deposits of coal at Carthage and other places farther north, but the prospects have not been developed.

SAN ACACIA RESERVOIR.

The narrow gorge at San Acacia is one of the proposed dam sites of the Rio Grande region. The broad Belen Valley, to the north, narrows abruptly at this point on account of the sheet of basalt which here covers the detritus. Measurements made at this point by Mr. R. H. Chapman, of the United States Geological Survey, indicate that a dam 50 feet high would be 1,200 feet in length and would flood about 18 square miles to an average depth of 25 feet, thus impounding about 288,000 acre-feet of water. A higher but longer dam might be constructed, but the maximum possible height is less than 75 feet above the river bed, the limiting factor being the broad sand gap to the northwest, the surface of which is about 75 feet above the river level.

Probably the most serious objection to San Acacia Gorge as a dam site is found in the nature of the rock. The hard basalt, which maintains the steep walls of the gorge, is a comparatively thin sheet resting on unconsolidated sand and gravel, cut by basalt dikes representing the vents through which the material of the sheet was extruded. Judging from surface indications, there is little prospect of finding solid rock sufficiently near the surface to be useful as a foundation for a dam, and the loose gravels would probably allow serious loss of impounded waters by leakage.

SAN FELIPE RESERVOIR.

Little can be added to the published description[a] of this gorge as a reservoir site. The proposed dam would be 2,350 feet long and would submerge only 1,511 acres. San Felipe gorge is similar to that at San Acacia in being formed by flows of basalt capping unconsolidated sands and gravels. At this point there are two flows of basalt separated by a few feet of sand, as shown in the cross section of White

[a] Newell, F. H., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 4, 1901, pp. 275–276.

Rock Canyon, given in fig. 2. The material to an unknown depth beneath the lava sheet is sand and gravel, rendering the gorge undesirable as a dam site.

ESPANOLA RESERVOIR.

The Espanola dam site, located at the head of White Rock Canyon' has been described[a] as consisting of clay beds in which blocks of basalt are embedded, the unconsolidated material extending indefinitely beneath the bed of the river. Near this site thick beds of rhyolite tuff, west of the river, and basalt, to the east, rest on the detrital beds, as shown in the section forming fig. 2 and in Pl. IV, *B*. The absence

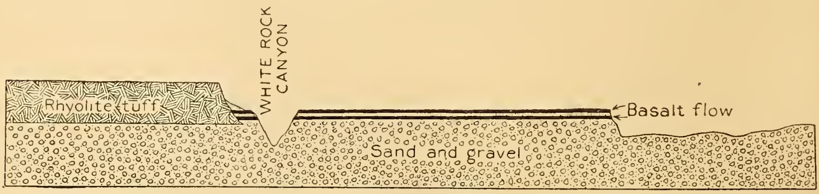


FIG. 2.—Section across White Rock Canyon near Espanola dam site.

of bed rock near the surface makes this locality of doubtful value as a dam site.

The proposed reservoir covers 5,437 acres and has a capacity of 186,861 acre-feet.

WATER SUPPLY.

SURFACE WATERS.

RAINFALL.

On account of the great differences in altitude of places that lie within short distances of one another in the Rio Grande region the amount of rainfall varies greatly from place to place, the mountain peaks serving as foci about which local storms gather. Few storms occur in which precipitation is uniform over a large area. The greater part of the rain falls as local showers close to the hills in which they originate. This fact is indicated quantitatively in the following table of rainfall, in which the stations nearest the hills show the greatest precipitation. At Santa Fe, situated at the base of the Rocky Mountains, the average yearly precipitation is 14.56 inches, while at San Marcial, situated near the center of the Rio Grande region and far from high mountains, the average is 4.84 inches and the minimum is only 1.17 inches.

[a] Newell, F. H., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 4, 1901, pp. 265-269.

TABLE 1.—*Rainfall in the Rio Grande region, New Mexico, in inches.*

Locality.	1896.	1897.	1898.	1899.	1900.	1901.	1902.	1903.	1904.	1905.	Average for the years recorded.
Albuquerque	7.02	9.74	6.39	(7.45)	5.90	10.19	4.94	5.83	6.82	4.20	6.85
Bernalillo	7.89	11.49	5.82	6.89	4.89	......	......	......	......	......	7.39
Cambray	......	......	......	......	......	7.71	6.64	8.02	11.46	......	5.96
El Paso	9.79	12.41	6.16	7.30	7.95	8.68	10.15	16.63	11.30	17.80	10.82
Engle	10.84	16.89	14.38	7.72	6.03	8.49	......	......	......	......	10.72
Espanola	8.08	......	7.78	6.25	10.20	......	......	......	......	......	8.08
Galisteo	12.22	......	9.30	(11.59)	......	16.49	......	......	......	......	12.30
Hillsboro	12.21	17.13	10.54	4.60	6.43	......	......	......	......	......	10.18
Los Lunas	7.65	......	......	......	6.05	......	......	......	10.45	......	8.71
Mesilla Park	7.99	8.96	11.21	9.67	8.40	11.96	10.90	10.29	10.13	17.09	10.65
Rincon	......	11.74	11.13	......	......	......	......	......	......	......	11.44
San Marcial	6.55	......	......	6.78	......	1.17	......	......	......	......	4.84
Santa Fe	14.28	20.40	12.97	10.15	15.89	17.41	13.36	9.79	14.19	17.22	14.56
Socorro	......	10.61	......	7.71	7.05	10.06	......	......	......	22.40	11.57

General average for the Rio Grande region 9.57

EVAPORATION.

Evaporation throughout the Rio Grande Valley greatly exceeds the rainfall. Records for only three years are obtainable, but these were made near the extremities of the region here considered, and probably represent adequately the evaporation for the entire area. The first was made at the International dam site near El Paso during the year 1890.[a] Those for the years 1900 and 1903 were made at the Climatological Laboratory of the University of New Mexico at Albuquerque.[b]

TABLE 2.—*Evaporation in the Rio Grande region, in inches.*

	At International reservoir site for 1890.	At Albuquerque for 1900.	At Albuquerque for 1903.		At International reservoir site for 1890.	At Albuquerque for 1900.	At Albuquerque for 1903.
January	2.0	2.04	1.81	August	11.4	10.21	11.73
February	2.0	2.63	2.07	September	9.2	8.00	9.65
March	7.0	6.17	5.21	October	6.8	4.38	6.62
April	7.3	6.82	10.05	November	4.6	1.73	4.21
May	10.8	10.08	10.98	December	2.9	1.40	1.88
June	11.2	12.63	11.33				
July	9.6	11.78	12.36	Total	84.8	77.87	87.90

Average for three years, 83.5.

DRAINAGE.

The drainage area of the Rio Grande north of El Paso, according to the reports of stream measurements made by the United States Geological Survey, is 38,000 square miles, of which 7,695 square miles lie north of Cenicero, Colo., leaving about 30,000 square miles as the area of the drainage basin within New Mexico.

The Rio Grande is mainly a flood-water stream and is subject to great fluctuations in volume. Its permanent flow is slight and is

[a] Thirteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1890-91, p. 411.

[b] Weinzirl, John, Bull. Hadley Climatological Laboratory, Univ. New Mexico, vol. 11, No. 10, 1905, pp. 5-8.

derived mainly from the mountains north and east of the area described. The tributaries within the Rio Grande region yield little permanent supply, although Galisteo Creek and Rio Puerco contribute small volumes of water during the greater part of the year. Many of the tributary channels carry small permanent streams near their heads in the hills, but the water in most of these sinks beneath the surface before reaching the river.

The floods that supply the greater part of the flow of the Rio Grande are of two general kinds, one due to the annual melting of snows in the mountains, often accompanied by general rain storms, the other due to local showers or "cloud-bursts." The first occur regularly, but those due to local showers are very irregular, both in volume and in time of occurrence. Sometimes the river bed is dry for several months and at other times it carries disastrous floods, the yearly discharge, for example, at El Paso, varying from 50,768 to 2,011,794 acre-feet, or a proportion approximating 1:40.

The records of discharge kept by the Geological Survey since 1897 at El Paso, San Marcial, and Ildefonso, and since 1899 at Cenicero, near the Colorado and New Mexico boundary, are as follows:

TABLE 3.—*Monthly discharge of the Rio Grande, in acre-feet.*

EL PASO, TEX.

Month.	1897.	1898,	1899.	1900.	1901.	1902.	1903.	1904.	1905.
January	18,754	30,129	12,912	8,110	278	8,291	615	972	35,920
February	10,774	33,655	11,330	5,680	4,502	5,772	1,289	387	43,309
March	4,427	20,044	7,071	460	3,669	635	22,602	0	188,489
April	103,537	97,944	8,807	300	0	7,904	49,468	0	197,911
May	511,088	140,192	10,330	44,810	158,102	526	203,623	0	545,950
June	362,677	111,570	0	93,100	77,038	307	586,909	0	851,147
July	81,770	196,269	19,553	70	12,576	20	158,202	0	58,800
August	8,116	31,236	430	0	60,655	14,499	4,334	7,398	19,785
September	41,950	2,262	0	16,483	21,005	9,313	1,031	10,959	3,322
October	108,096	160	123	0	5,336	1,428	2,033	366,486	4,225
November	67,359	119	119	0	12,813	298	298	48,397	25,458
December	41,812	5,718	2,828	738	7,993	1,775	2,440	38,182	37,478
Year	1,360,360	669,298	73,503	169,751	363,967	50,768	1,032,844	472,781	2,011,794

Total for nine years, 6,205,066; average for nine years, 689,452.

SAN MARCIAL, N. MEX.

Month.	1897.	1898.	1899.	1900.	1901.	1902.	1903.	1904.	1905.
January	19,553	57,675	27,854	40,582	24,718	22,731	17,197	16,840	39,114
February	24,325	59,425	24,603	35,099	25,468	17,435	21,927	18,902	63,868
March	40,767	62,164	27,546	33,203	15,114	7,954	46,790	6,060	217,904
April	212,548	271,458	54,089	6,248	23,683	40,106	100,007	0	279,392
May	755,196	165,832	35,048	123,590	256,126	26,787	318,367	0	962,221
June	366,426	126,268	952	159,888	96,178	6,407	660,476	0	714,268
July	65,977	167,062	28,407	123	59,286	0	77,841	10,532	35,782
August	6,149	13,835	6,395	0	65,534	49,210	3,064	55,974	20,093
September	114,188	4,641	2,916	73,190	37,607	13,349	1,438	44,727	5,276
October	281,677	1,230	676	123	17,018	823	545	463,240	7,349
November	175,715	11,722	9,521	2,440	20,053	4,641	5,534	51,769	42,397
December	152,736	23,365	21,828	10,084	19,240	11,286	18,883	41,752	34,344
Year	2,215,257	964,677	239,835	484,570	660,025	200,729	1,272,069	709,796	2,422,008

Total for nine years, 9,168,966; average for nine years 1,018,774.

TABLE 3.—*Monthly discharge of the Rio Grande, in acre-feet*—Continued.

ILDEFONSO, N. MEX.

Month.	1897.	1898.	1899.	1900.	1901.	1902.	1903.	1904.	1905.
January	28,715	21,705	26,009	36,770	24,410	29,643	23,127	20,910	43,470
February	30,101	24,936	35,599	32,322	36,543	27,183	24,724	24,220	51,590
March	60,750	33,449	81,164	52,818	45,624	33,709	75,193	21,340	158,100
April	303,113	265,864	176,430	51,531	83,425	97,577	172,324	27,310	218,900
May	702,254	200,328	117,687	211,517	319,367	73,567	406,612	24,160	785,200
June	366,128	223,973	23,742	173,395	130,850	28,215	709,468	17,020	572,700
July	97,274	161,590	36,647	18,262	44,824	16,730	136,780	15,130	53,740
August	27,423	39,168	22,197	10,145	50,850	34,165	26,563	91,990	38,680
September	40,463	19,279	53,137	42,605	34,512	28,790	22,314	148,300	23,150
October	136,196	21,890	26,563	23,796	30,190	17,157	21,828	252,800	25,950
November	71,881	35,583	44,985	25,289	27,491	18,386	25,170	49,450	37,960
December	32,220	39,168	38,184	29,022	28,468	19,220	23,611	35,420	37,940
Year	1,896,518	1,086,933	682,344	707,472	856,554	424,342	1,667,714	728,050	2,047,380

Total for nine years, 10,097,307; average for eight years, 1,121,923.

CENICERO, COLO.

Month.	1899.	1900.	1901.	1902.	1903.	1904.	1905.
January	(a)	39,229	36,524	32,035	1,537	18,820	59,640
February	(a)	42,153	32,267	42,097	1,388	23,990	66,370
March	(a)	35,847	22,443	33,757	2,091	7,563	53,490
April	(a)	20,826	16,542	18,744	18,684	9,104	44,270
May	(a)	87,927	103,299	30,129	123,713	1,322	399,300
June	(a)	84,734	61,408	6,783	379,339	1,208	507,600
July	2,582	1,783	5,041	1,353	72,432	1,076	15,860
August	3,259	1,353	3,689	1,045	2,890	8,608	9,469
September	6,069	1,845	2,975	1,547	5,355	11,660	3,725
October	7,194	2,275	3,320	1,968	3,935	97,770	6,044
November	15,412	9,223	4,284	1,785	12,674	24,750	12,850
December	19,553	35,109	20,721	2,275	18,569	53,310	31,730
Year	....	362,304	312,513	173,518	642,607	259,181	1,210,000

a No record.

Total for six years, complete, 2,960,123; average for six years, 493,354.

UNDERGROUND WATERS.

The Rio Grande region embraces several more or less separate geologic provinces and the underground-water resources may be most conveniently described by districts.

SANTA FE DISTRICT.

The Santa Fe district is located in the Rocky Mountains region on the Rio Grande north of Galisteo Creek. The strata, composed of partially consolidated sands, gravels, and beds of mountain wash of Tertiary age, dip to the west away from the mountains. The inclination of the strata and their exposure in the region of greatest precipitation within the area described are favorable to the occurrence of artesian water.

Only two deep wells have been sunk in these deposits, and in neither of them was water found under notable pressure. The first one, drilled several years ago in search of artesian water, is 8 miles south of Santa Fe. In this no surface flow was obtained. The second, drilled in 1905 at the Santa Fe Indian School, is a 12-inch well, 989 feet deep, and penetrates angular wash principally except for 75 feet of conglomerate encountered at a depth of 225 feet. Water was found at a depth of 100 feet and rose 44 feet, but its volume is small and the supply is easily exhausted by pumping. Water was also obtained in the 75 feet of conglomerate and in several thin gravel strata not recorded. This well is on comparatively high ground, its altitude being about 7,000 feet, and near the eastern or highest part of the detrital formation. It is probable that on lower ground, nearer the river, water might be found under pressure sufficient to produce surface flows. Water emerges from this formation as springs along the river at an altitude about 1,500 feet lower than that at Santa Fe and along the lower reaches of Santa Fe Creek. At La Cienaga, 12 miles southwest of Santa Fe and about 700 feet lower, there are several springs of sufficient volume to irrigate a considerable tract of land.

Record of well at Santa Fe Indian School.

	Feet.
Mountain wash	0–225
Conglomerate	225–300
Mountain wash	300–989

ALBUQUERQUE DISTRICT.

The Albuquerque district may be considered as extending from Galisteo Creek southward to Isleta. The geologic formations, so far as they have been penetrated by wells, are composed of unconsolidated material and carry no water under pressure. Water saturates the flood-plain material to the level of the river and is found in abundance wherever wells penetrate to that level.

A few wells sunk on the "mesa" east of Albuquerque obtain water at horizons somewhat higher than that of the river. A well at the University of New Mexico,[a] 1 mile east of Albuquerque, is 240 feet deep and contains water at a depth of 200 feet, about 20 feet higher than the river level, while the "military well," 7 miles east of Albuquerque, contains water at a depth of 420 feet, or about 130 feet above the river level.

The deepest well in this district, 710 feet, is in Albuquerque, at the city waterworks. It is a 12-inch double-steel-cased well, to which water is admitted only below a depth of 350 feet. In addition to this deep well the water company owns seven 6-inch wells and one 12-inch well, each 291 feet deep, and a 65-foot dug well, from the bottom of which 25 pipes are driven to depths of 35 feet, the water being admitted only from the bottom of these pipes, or 100 feet below the surface.

[a] Weinzirl, John, Bull. Hadley Climatological Laboratory of University of New Mexico, vol. 10, 1905, p. 12.

All the wells together yield an average of 3,000,000 gallons a day, or 2,083 gallons a minute.

The 710-foot well has been tested alone and yielded 600 gallons a minute, with a local depression of the water surface within the well of 18 feet.

Record of the city waterworks well at Albuquerque, N. Mex.

	Feet.
Soil	0– 10
Sand and coarse gravel	10– 35
Clay	35– 40
Sand and coarse gravel	40– 71
Cemented sand	71– 75
Clay	75– 80
Cemented sand and bands of "sandstone"	80–179
Sand and gravel	179–185
Clay	185–189
Cemented sand and clay	189–243
Yellow clay	243–292
Cemented sand	292–320
Yellow clay	320–362
Sand and clay	362–386
Shale and sand	386–397
Cemented sand	397–442
Yellow clay	442–456
Cemented sand	456–471
Sand and clay	471–487
Clay, sand, and gravel	487–572
Quicksand	572–614
Clay and cemented sand	614–710

BELEN DISTRICT.

GENERAL CONDITIONS.

The Belen district extends from Isleta southward to a point a few miles north of Socorro, where the Rio Grande Valley narrows between the encroaching hills, as shown in Pl. I. Through the center of this district extends the erosion basin known as Belen Valley. The surface of the broad flood plain formed by the deposits flooring the valley stands only a few feet above the river bed, and the material composing the deposits is saturated with water. Shallow wells throughout the bottom land reach this water at depths of 5 to 15 feet and readily obtain it in large quantity.

WELLS.

The Atchison, Topeka and Santa Fe Railway Company's well, 1.5 miles south of Belen, is the only one within this district from which a large and constant supply is pumped. It is a dug well, 15 feet deep and 20 feet in diameter, and contains 7 feet of water. It has yielded

50,000 gallons a day, and would probably yield more if necessary. The well is situated on the flood plain of the river in gravel and coarse sand, and the water level in the well rises and falls with that of the river.

No important deep wells have been sunk on the lowlands of the Belen district. One at the Belen flour mill, 35 feet deep, owned by John Becker, and another at the Catholic Church, 85 feet deep, are the deepest.

Three deep wells have been bored in the mesa gravels. One at Colorado siding, on the Atchison, Topeka and Santa Fe Railway branch, known as the Belen cut-off, is 500 feet deep and contains 34 feet of water. This well is 9 miles southeast of Belen (altitude, 4,788 feet), at an elevation of 5,012 feet, or 224 feet higher than Belen, the water level in this well being 234 feet lower than the water at Belen.

Record of Atchison, Topeka and Santa Fe Railway Company's well at Colorado siding, New Mexico.

	Feet.
Soil	1–24
Sand	24–290
Light-colored clay	290–340
Red sandy clay	340–500

At Becker siding, 15 miles southeast of Belen, the railway company has a 6-inch bored well, 427 feet deep, with water standing 364 feet below the surface. The altitude at the well is 5,140 feet, or 352 feet above Belen, making the water level in the well 4 feet lower than that in the valley at Belen.

Record of Atchison, Topeka and Santa Fe Railway Company's well at Becker siding, New Mexico.

	Feet.
Cemented gravel	0–100
Red clay	100–150
Red clay and gravel	150–275
Red clay	275–290
Red clay and gravel	290–300
Red clay and gravel, with bowlders	300–340
Gravel	340–345
Red clay and gravel, with bowlders	345–378
Gravel	378–388
Red clay and gravel	388–400
Water bearing gravel	400–420
Gravel and clay	420–427

At Sandia, a siding on the main line of the Atchison, Topeka and Santa Fe Railway, west of Isleta, the railway company bored a 12-inch well 893 feet deep during the summer of 1905. It is in sand, gravel, and clay throughout, and encountered water at a depth of 445 feet.

Record of Atchison, Topeka and Santa Fe Railway Company's well at Sandia, N. Mex.

	Feet.
Unconsolidated sand	0–340
Sand, with clay bands	340–400
Clay	400–440
Sand	440–480
Gravel	480–490
Sand, with clay bands	490–530
Sand	530–585
Clay	585–640
Sand and clay	640–893

JORNADA DISTRICT.

GEOLOGIC STRUCTURE.

The Jornada district extends from San Marcial to Las Cruces, between the San Andreas and the Caballos-Fra Cristobal mountain ranges. The geologic structure of the Jornada del Muerto has been described[a] as a syncline, in which the older or consolidated rocks pass underneath the unconsolidated material which covers the surface.

Along the eastern base of the Caballos-Fra Cristobal range the upturned Cretaceous sandstones are truncated and exposed in such a way as to freely admit the water crossing them as streams from the mountains, as well as that falling upon them as rain. These sandstones are not exposed elsewhere within the Jornada district, and it is uncertain whether they occupy the entire trough of the syncline, as stated by Keyes.[b]

The Jornada del Muerto, as has been previously stated, is probably a part of the old Rio Grande Valley that has been filled with unconsolidated sands and gravels of comparatively recent origin. This material has been penetrated by wells to a depth of 360 feet, but its total depth has not been determined and very little is yet known of the underground conditions in this region. The Cretaceous sandstones may extend without interruption beneath the detrital filling, or, if they were originally present, may have been largely eroded away previous to the deposition of the detritus.

FLOWING WELLS.

In the vicinity of Engle flowing water is obtained from three wells, which penetrate the Cretaceous sandstones. One about 10 miles northwest of Engle, near the base of the Fra Cristobal Mountains, is said to be 260 feet deep. The flow is not sufficient to water a few hundred cattle for which it is used, and the water is pumped to increase the yield.

---

[a] Keyes, C. R., Water-Sup. and Irr. Paper No. 123, U. S. Geol. Survey, 1905.
[b] Ibid., p. 10 (geologic map).

The other wells belong to the Santa Fe Railway Company and the water is pumped to Engle for railway use. The wells are located in the canyon leading from Engle to the Rio Grande. One near old Fort McRae was drilled to a depth of about 1,200 feet in search of coal. No coal was found, but water was encountered under pressure sufficient to produce a considerable surface flow but not great enough to raise it to the level of the town. From this well and a second one put down about 2 miles farther east water is pumped into a reservoir on the Jornada, from which it flows to Engle by gravity.

NONFLOWING WELLS.

A number of wells have been bored in the Jornada del Muerto, but definite records of only a few of them are obtainable. Those near the western border of the plain, along the railroad, penetrate the Cretaceous sandstones and find water under slight pressure, but the greater number have been bored in depressions along the center of the plain and penetrate only unconsolidated sand, gravel, and wash. The record of Mr. Linger's well may be taken as representative of the material found in the center of the Jornada.

Record of well of G. W. Linger & Company, 5 miles east of Upham.

	Feet.
Red clay	1–10
Cement	10–19
Sand and silt	19–235
Bowlders (maximum diameter, 8 inches)	235–240

Partial records obtained of a few of the wells are given in the following table:

TABLE 4.—*Records of bored wells in the Jornada del Muerto.*

Owner.	Location.	Total depth	Depth to water.	Power used.	Remarks.
		Feet.	*Feet.*		
J. D. Isaacks	Sec. 35, T. 20 S., R. 2 E.	265	250	Wind	Penetrates 35 feet soil; 23 feet sand and gravel
Do	Sec. 25, T. 21 S., R. 2 E.	330	292	Gasoline	In sand and gravel.
Do	Sec. 13, T. 20 S., R. 2 E.	115	95	Wind	
J. W. Taylor	Sec. 17, T. 19 S., R. 2 E.	360	345	do	Penetrates 345 feet angular material, with 15 feet rounded bowlders.
A., T. and S. F. Rwy	8 miles west of Engle	1,200	Flow.	Gasoline	In sandstone and shale.
Do	2 miles south of Upham.	480	140	Steam	
Do	1 mile west of Alaman	400	No water		
L. Baldwin & Co.	Alaman	140	140	Steam	Water raised 100 feet.
Victoria Land and Cattle Co	4 miles north of Engle	200			In red sandstone.
Do	10 miles north of Engle	500	492	Gasoline	Water raised 327 feet.
G. W. Linger & Co.	5 miles northeast of Upham.	240	236	do	Sand and gravels (maximum 6 inches in diameter) at bottom. Water raised 102 feet.
Mr. Turner	18 miles east of Rincon	350	300(?)	do	In sand and gravel.

INDICATIONS OF ARTESIAN WATER.

The occurrence of water under pressure in several wells near Engle indicates the presence of artesian conditions beneath a small area of the Jornada, but in areas lying beyond the immediate vicinity of Engle the presence or absence of artesian water must be inferred entirely from surface indications. Since water is found in the Cretaceous sandstones near Engle it might be expected in wells that penetrate these sandstones elsewhere, provided the sandstones extend uninterruptedly beneath the surface in this region. Their extent, however, and their depth beneath the surface over the greater part of the Jornada are unknown.

The water in the unconsolidated gravel beds may perhaps be confined beneath impervious layers, since the Jornada del Muerto slopes southward at an average rate of 4½ feet to the mile, but nothing now known proves either the presence or absence of such layers. The surface indications are moderately favorable to the occurrence of artesian water in certain areas, particularly at the southern end of the Jornada and still farther south, in the Mesilla Valley.

LA MESA DISTRICT.

La Mesa district lies in the southern part of the Rio Grande region west of Mesilla Valley. Wells have been sunk in various parts of this district, both for railroad use and for stock purposes. No solid rock was encountered in any of the wells, most of which find water in abundance, but at a considerable depth, as indicated in Table 5. The deepest well on La Mesa, 945 feet, was bored by the Southern Pacific Railway Company at Lanark. The company owns two other wells at the same place, one 648 feet and one 615 feet deep, the three yielding 50 gallons of water a minute. The material penetrated is sand with small waterworn pebbles, and contains water below a depth of 380 feet.

Since the altitude of Lanark is 4,156 feet, the altitude of the water surface is 3,776 feet, while that at Bosque Seco, in Mesilla Valley, 15 miles northeast of Lanark, is 3,800 feet—24 feet higher than at Lanark. At Noria, the altitude of which is 4,114 feet, the water surface, 358 feet below the surface of the land, is 3,756 feet above sea level. In the 12 miles between Lanark and Noria the water surface inclines to the south 20 feet, or at an average rate of 1.7 feet per mile. A line drawn through Bosque Seco, Lanark, and Noria would run somewhat west of the center of the old débris-filled valley of the Rio Grande for a distance of 27 miles. Along this line there is a fall of the water surface of 44 feet, or an average of 1.7 feet per mile. The gradient of the water table in Mesilla Valley between Bosque Seco (3,800 feet) and the southern end of

Mesilla Valley (3,680 feet), a distance of about 32 miles, is 3.7 feet per mile. It is evident from these facts that the surface of the underground water has a regular gradient down the old channel through La Mesa, although it is less than the gradient of the river. A line of wells a few miles farther east in the center of the old valley would probably show a steeper gradient of the water plane.

The facts upon which the determination of gradient rests are not sufficiently numerous to make it conclusive. The depths to water determined and the indications that La Mesa is a part of the ancient débris-filled valley naturally leads to the inference that the course of the underflow should be southward through the detritus of La Mesa. It is possible, on the one hand, that additional data will show a gradient steeper than 1.7 feet per mile. On the other hand, it is possible that the original course of the underflow down the old channel has been reversed by reason of the down cutting of the river in Mesilla Valley and the accumulation of surface water in the gravels of La Mesa. The latter possibility is strengthened by the facts that La Mesa is nearly level and the material so porous that rain enters it without producing even temporary streams.

TABLE 5.—*Records of bored wells in La Mesa district.*

Owner.	Location.	Total depth.	Depth to water.	Power used.	Material encountered.
		Feet.	*Feet.*		
Henry Brock	Sec. 30, T. 25 S., R. 2 W.	240	221	Gasoline	Sand and waterworn gravels.
Do	Sec. 7, T. 24 S., R. 1 W.	430	386	do	Do.
Do	T. 24	515			Clay.
Mr. Hawkins	5 miles west of Picacho Mountain.	218	170	Gasoline	
Robert Herrington	2 miles northwest of Noria.	435	350	do	Sand and gravel.
J. F. Kilburn	T. 27 S., R. 1 W.	[a] 478	408		Do.
Do	6 miles northwest of Lanark.	388	370	Gasoline	Sand and waterworn gravel.
S. P. Rwy. Co	Lanark	945	380	Steam	Do.
Lewis Bros	5 miles northeast of Lanark.	365	340	Gasoline	Sand and gravel.
J. B. Stahling	10 miles west of Lanark.	[b] 460	440		
Do	6 miles west of Lanark	350	311	Gasoline	
El Paso and S. W. Rwy.	Potrillo	240	220	do	Sand and clay.
Do	Noria	438	358	do	Sand and gravel.

[a] 170 feet in bottom of crater. [b] 200 feet in bottom of crater.

MESILLA DISTRICT.

LOCATION AND CHARACTER.

The Mesilla district is confined to Mesilla Valley, the southernmost of the erosion basins of the Rio Grande region. During floods the river submerges a large part of the valley floor, a level flood plain formed by the deposition of silt and fine sand. As previously stated (p. 24), Mesilla Valley was once deeper than it is now, and has been recently filled to some extent by flood-plain deposits. The geologic formations and their relation to one another are indicated in the sections on Pl. III. The rock basin was partly filled with débris, in which a secondary valley was eroded and later partly filled with sand and silt.

WATER TABLE.

Underground water is found throughout Mesilla Valley at practically the river level. The depth to water was measured in the wells in the valley, and the results were plotted on the contour maps prepared by the United States Reclamation Service, and from these the map forming Pl. X has been prepared, which shows by contours the depth to water.

The water table changes position to some extent, according to changes in the volume of water in the river. Professor Slichter[a] has shown that the ground water of the valley is derived largely from the river and that the gradient of the water plane in a direction parallel to the river is practically constant at 4.64 feet per mile where measured near Mesilla Park, while the gradient away from the river varies from 0.4 foot per mile during low water to 2.3 feet in times of flood. A rise of the water table of 5 feet is reported near the river during the six months for which records were kept.

WELLS OF MESILLA VALLEY.

General statements.—A number of wells have been bored in Mesilla Valley for pumping water in large quantities, mainly for irrigation. Twelve of these have been carefully tested by Professor Slichter[b] with a view to ascertaining their capacity, the cost of pumping, etc. Some of his results are included in Table 6 (p. 47). It should be noted, in comparing the figures of the column showing depth to water with the map (Pl. X), in which depth to water is indicated by contours, that these wells are usually placed on ground high enough to allow the water to flow over the land to be irrigated. The depth to water is therefore somewhat greater than the average depth indicated on the map.

Wells at Agricultural College.—Several wells have been bored for the Agricultural College at Mesilla Park.

A bored well at the college building is 75 feet deep and 4 inches in diameter. Water was encountered at a depth of 43 feet in 1896, but in 1903 it was found to have lowered to 53 feet.

Another 4-inch well at the college machine shop is 120 feet deep. Saline water was found at this depth and the pipe was drawn back to 75 feet, where better water was found.

An irrigation plant was established in 1902 at the experiment station of the Agricultural College, consisting of one 12-inch and one

---

[a] Slichter, C. S., Observations on the ground waters of Rio Grande Valley: Water-Sup. and Irr. Paper No. 141, U. S. Geol. Survey, 1905, pp. 22-29.

[b] Slichter, C. S., ibid., p. 34.

6-inch well, each 48 feet deep. This plant has been described by members of the college faculty[a] in a bulletin of the experiment station. The wells penetrate gravel beds, from which water is readily obtained, the yield being about 1,000 gallons a minute.

Record of experiment station well.

	Feet.
Soil	0– 5
Sand	5–32
Sand and gravel	32–47
Sand	47–48

During the summer of 1905 a pumping plant was installed on the horticultural farm near Mesilla Park station. A 12-inch well was bored 62 feet deep and an 18-foot strainer was placed at the bottom. A pit 8 feet square was dug to water level, 19 feet below the surface. It contains a centrifugal pump with gasoline engine, which discharges 1,000 gallons of water per minute.

Wells of F. C. Barker.—Mr. Barker has three pumping plants. One, at Las Cruces, pumps from a 6-inch well 53 feet deep, which is capable of supplying about 150 gallons of water per minute. The well penetrates a gravel bed 35 feet thick, which supplies the water.

Record of F. C. Barker's well at Las Cruces

	Feet.
Soil	0– 3
Sand	3–18
Gravel and bowlders	18–53

Mr. Barker's second pumping plant is situated about 1 mile south of Las Cruces and consists of a 6-inch well 48 feet deep, supplied with pump and gasoline engine which raise 131 gallons of water per minute.

Record of F. C. Barker's well, 1 mile south of Las Cruces.

	Feet.
Soil	0– 8
Sand	8–16
Sand and gravel	16–30
Coarse gravel	30–48

A third plant is reported to have been established during the summer of 1905 near the second. An 8-inch well was bored to a depth of 85 feet and supplied with centrifugal pump and gasoline engine, which raise a volume of water estimated at 800 gallons per minute.

Record of F. C. Barker's 8-inch well.

	Feet.
Soil	0–17
Quicksand	17–36
Sand and gravel	36–58
Gravel and bowlders	58–75
Caliche	75–79
Sand and gravel	79–85

[a] Vernon, John J., and Lester, Francis E., Bull. No. 45, New Mexico College Agric. and Mechanic Arts, Mesilla Park, N. Mex., 1903.


Selden
Old Fort Selden
N
HEADGATES LAS CRUCES CANAL
Shalam
Dona Ana
RIO GRANDE
Las Cruces
Mesilla
College A. & M. A.
Mesilla Park
Bosque Seco
Old Ft. Fillmore
Santo Tomas
San Miguel
Mesquite
La Mesa
Earlham
Berino
Chamberino
RIO GRANDE
NEW MEXICO
TEXAS
Anthony
BOUNDARY LINE
La Union
Vinton
Canutillo
Montoya
Whites Spur
NEW MEXICO
MEXICO
BOUNDARY LINE
MAP OF
MESILLA VALLEY
NEW MEXICO
Scale in miles
5 0 5 10 15
Pumping plants
Water contours

Well of Mrs. E. M. Boyer.—Mrs. Boyer's well is located on her ranch, about one-fourth mile north of the railroad station at Las Cruces. It is a 6-inch bored well, 52 feet deep, with a 12-foot strainer. Water is raised by a centrifugal pump and 12-horsepower gasoline engine at the rate of 658 gallons per minute.

Record of Mrs. E. M. Boyer's well.

	Feet.
Soil	0- 2
Sand	2-22
Sand and gravel	22-52

Well of Frank Burke.—Mr. Burke's well is located one-half mile south of Mesilla Park. It is a 12-inch well, 60 feet deep, with a 12-foot strainer. Water is raised by a centrifugal pump and 21-horsepower gasoline engine at the rate of 755 gallons per minute.

Record of Frank Burke's well.

	Feet.
Soil	0- 8
Sand	8-22
Sand and gravel	22-60

Well of J. C. Carrera.—Mr. Carrera's well is located about 1 mile south of Las Cruces. It is a 6-inch well, 58 feet deep, with a 15-foot strainer. Water is raised by a centrifugal pump and 8-horsepower gasoline engine at the rate of 648 gallons per minute.

Well of Robert Elwood.—Mr. Elwood, of Las Cruces, constructed a pumping plant for irrigation during the summer of 1905, in which two 8-inch wells 40 feet apart are connected with a 5-inch centrifugal pump and 12-horsepower gasoline engine. The first well was bored 100 feet deep, but the casing was later withdrawn to the 64-foot level, where the most productive gravel bed occurs. The second well is 64 feet deep, and both are supplied with 24-foot strainers. The yield is estimated at 800 gallons of water per minute.

Record of Robert Elwood's well.

	Feet.
Sand and gravel	0- 32
Clay	32- 35
Sand and gravel	35- 50
Cemented sand	50- 52
Coarse sand and gravel	52-100

Well of W. N. Hager.—Mr. Hager's well is located one-half mile west of Mesilla Park. It is a 10-inch well, 63 feet deep, with a 12-foot strainer. Water is raised by a centrifugal pump and 12-horsepower gasoline engine at the rate of 325 gallons per minute.

Well of A. L. Hines.—Mr Hines's well is located 1 mile northeast of Mesilla. It is a 6-inch well, 59 feet deep, with an 8-foot strainer.

Water is raised by a centrifugal pump and 8-horsepower gasoline engine at the rate of 271 gallons per minute.

Record of A. L. Hines's well.

	Feet.
Soil	0–8
Sand	8–19
Quicksand	19–47
Sand and gravel	47–59

Wells of Horaco Ranch Company.—The Horaco Ranch Company has three wells separated by a few hundred feet and located west of Berino.

No. 1 is an 8-inch well, 75 feet deep, with an 18-foot strainer. Water is raised by a centrifugal pump and 12-horsepower gasoline engine at the rate of 837 gallons per minute.

No. 2 is a 10-inch well, 53 feet deep, with an 18-foot strainer. Water is raised by a centrifugal pump and 12-horsepower gasoline engine at the rate of 191 gallons per minute.

No. 3 is a 10-inch well, 62 feet deep, with an 18-foot strainer. Water is raised by a centrifugal pump and 12-horsepower gasoline engine at the rate of 750 gallons per minute.

Las Cruces city well.—During the summer of 1905 a pumping plant was constructed to furnish the city of Las Cruces with water. A 6-inch well was bored to a depth of 63 feet and an 18-foot strainer placed at the bottom of the pipe in a bed of gravel, occurring below the depth of 46 feet. A pit 8 feet square and 20 feet deep contains an Advance steam pump, which is placed 2 feet above normal water level. The water is drawn by suction from the capped casing at a rate of 300 gallons per minute.

The water drawn from a depth lower than 46 feet is apparently much better for domestic use than that obtained from the surface wells of Las Cruces. An analysis of the water made by Geo. W. Lord Company, of Philadelphia, Pa., is as follows:

Analysis of water from Las Cruces city well.

	Parts per million.		Parts per million.
Total solids	998	Chlorine (Cl)	133
Calcium (Ca)	156	Silica (SiO_2)	27
Magnesium (Mg)	19	Carbonate radicle (CO_3)	120
Sodium (Na)	159	Organic and volatile	Trace.
Sulfate radicle $(SO)_4$	338		

Well of Theodore Roualt.—Mr. Roualt's well is located on his ranch near the river, 3 miles northwest of Las Cruces. It is a 10-inch well, 48 feet deep, with a 10-foot strainer. Water is raised by a centrifugal pump and 18-horsepower steam engine at the rate of 351 gallons per minute.

Well of Shalam Colony.—Several years ago an elaborate pumping plant was constructed for irrigation purposes at Shalam Colony, west of Dona Ana. A circular pit 18 feet in diameter was sunk to a depth of 30 feet and its sides and bottom were cemented. In the bottom of this pit five wells were bored, three of which are 6 inches in diameter and 90 feet deep (60 feet below the bottom of the pit), one is 12 inches in diameter and 90 feet deep, and one 6 inches in diameter and 197 feet deep. At a depth of 90 feet there is a 3-foot gravel stratum, which apparently yields the greater part of the water. The sand beneath this stratum entered the pipe so freely that it was impracticable to draw water from horizons lower than 90 feet.

A storage reservoir, covering an area of 1 acre and 5 feet deep, was constructed, and into this a 60-horsepower steam engine pumps water at the rate of 1,500 gallons per minute.

The ground water at this place is 9 feet beneath the surface, making a normal depth of 21 feet of water in the pit. The pump lowers the water surface 18 feet to a level at which it remains stationary, the flow from the wells equaling the discharge of the pump.

Well of J. R. Thompson.—Mr. Thompson's well is situated at the eastern edge of the valley, about 2 miles south of Earlham. It is a 6-inch bored well, 138 feet deep, and obtains water from the coarse sand at the bottom of the well. An accurate driller's record was obtained as follows:

Record of J. R. Thompson's well.

	Feet.
Sand and silt	0– 80
Clay	80–100
Sand	100–118
Clay	118–128
Coarse sand	128–138

Well of G. H. Totten.—Mr. Totten's well is located 1 mile west of Mesilla. It is a 10-inch well, 62 feet deep, with 24 feet of strainer. Water is raised by a centrifugal pump and 28-horsepower gasoline engine at the rate of 464 gallons per minute. When tested the well contained only 12 feet of strainer, which had been placed in the upper sand layer. Later the well was lowered and a second 12-foot strainer was added, greatly increasing the flow.

Record of G. H. Totten's well.

	Feet.
Soil	0–17
Sand	17–51
Clay	51–53
Sand and gravel	53–62

Samples of the waters were taken from both sand layers of this well to ascertain if they varied in quality. The analyses, made by Prof.

R. F. Hare, of the New Mexico agricultural experiment station, indicate that the waters vary in the amounts, but not in the kinds of salts they contain, that from the upper sand containing 1,566 parts and that from the lower sand 1,123 parts of total solids per million parts of water.

Table showing well records in Mesilla Valley.—The following table comprizes data concerning wells in Mesilla Valley. Descriptions of pumping tests for the first twelve wells of the table may be found in Prof. Charles S. Slichter's paper on ground waters of Rio Grande Valley:[a]

[a] Water Sup. and Irr. Paper No. 141, U. S. Geol. Survey, 1905, pp. 51–73.

TABLE 6.—*Records of wells in Mesilla Valley.*

	Owner.	Location.	Total depth.	Depth to water.	Yield per minute.	Water lowered by pumping.	Specific capacity per minute.	Specific capacity per square foot of strainer per minute.	Size of well.	Power used.	Use.	Cost of water per acre-foot.	Total lift in feet.
			Feet.	*Feet.*	*Gals.*	*Feet.*	*Gals.*	*Gals.*	*In.*				
1	F. C. Barker	1 mile south of Las Cruces	48	14	131	22.48	5.83	0.337	6	Gasoline	Irrigation	$13.20	45.58
2	Mrs. E. M. Boyer	Las Cruces	52	20	658	19.76	33.30	1.969	6	do	do	3.47	40.30
3	F. Burke	½ mile south of Mesilla Park	60	14	755	22.85	31.75	.930	12	do	do	4.87	40.45
4	J. C. Carrera	2 miles north of Mesilla Park	58		648	8.48	74.60	3.530	6	do	do	3.16	26.85
5	W. N. Hager	½ mile west of Mesilla Park	63		325	15.20	22.30	.760	10	do	do	9.57	34.77
6	A. L. Hines	1 mile northeast of Mesilla	59	20	271	14.08	19.20	1.790	6	do	do	8.95	36.05
7	T. Roualt	3 miles northwest of Las Cruces	48		351	23.86	16.00	.620	10	do	do	7.91	34.16
8	G. H. Totten	½ mile west of Mesilla	62	17	464	22.50	20.60	.760	10	do	do	8.19	43.35
9	Agricultural College	Mesilla Park	48		1,000	11.37	88.00	2.320	12	Steam	do	4.70	29.55
10	Horaco Ranch Co. No. 1	Berino	75	5	837	13.75	60.80	1.690	10	Gasoline	do	2.21	23.89
11	Horaco Ranch Co. No. 2	do	53	8	191	23.64	8.10	.178	10	do	do	10.90	35.26
12	Horaco Ranch Co. No. 3	do	62	8	750	18.55	40.40	.892	10	do	do	2.46	32.36
13	Academy Loretto	Las Cruces	66	26	300					do	Domestic		
14	P. S. Ames	do	51	21	130					do	Irrigation		
15	A., T. & S. F. Rwy	Earlham	25	10	40				120	Wind	Engines		
16	Agricultural College	Mesilla Park, west of railway	62	19	1,000				12	Gasoline	Irrigation		
17	F. H. Bascom & Co	Las Cruces	46	35	30				4	do	Factory		
18	F. C. Barker	Las Cruces, near station	53	18	150				6	do	Irrigation		
19	do	1 mile south of Las Cruces	85	16	800				8	do	do		
20	S. F. Bean	Las Cruces	64	34	35				6	do	do		
21	Catholic Church	do	36	34	50				Dug	do	do		
22	City waterworks	do	63	22	300				6	Steam	City		
23	R. Elwood	do	100	17	800				8	Gasoline	Irrigation		
24	W. S. Gilliam	Mesilla Park	52	16	800				10	do	do		
25	Doctor Lane	5 miles east of Fort Fillmore	260	Dry					6				
26	do	6½ miles east of Fort Fillmore	330	Dry					6				
27	L. Quintero	1 mile south of Las Cruces	35	20					6	Steam	Irrigation		
28	Shalam Colony	Las Cruces	197	9	1,500				6	do	do		
29	S. A. Steele	1 mile south of Las Cruces	83	17					8	Gasoline	do		
30	W. G. Stewart	2 miles north of Las Cruces	35	25	30				2	do	do		
31	J. B. Thompson	2 miles southeast of Earlham	138						6	Windmill	Domestic		

UNDERFLOW OF THE RIO GRANDE REGION.

WATER PLANE.

In Mesilla Valley the surface of the ground water is practically at the river level, as has been previously stated. The water plane in the valleys farther north can not be accurately represented for lack of detailed topographic maps, but the depths to water in wells situated in the bottom lands throughout the Rio Grande region indicate that the surface of the ground water is always at or very near the river level. The water plane determined for Mesilla Valley and mapped in Pl. X is probably typical, and the map doubtless expresses with sufficient accuracy the relation of the water table to the river and to the land surface for the entire region.

QUANTITY OF UNDERFLOW.

The investigation of the quantity and rate of underflow in Mesilla Valley, carried on in 1904 by Professor Slichter,[a] shows (pp. 11–13) that there is practically no underflow through the canyon near El Paso, but (pp. 25–29) that near Mesilla Park, where a series of experiments were made, water enters the underflow both from the river and from the drainage of the mesas. His conclusions are tabulated as follows:

TABLE 7.—*Amount of water contributed to the underflow of the Rio Grande near Mesilla Park, N. Mex., between September 20 and October 23, 1904.*

Dates.	Number of days.	Amount of ground water contributed by each mile of the river.			Amount of ground water contributed by rainfall upon mesa east of the valley per mile of river valley.		
		Cubic feet of water per 24 hours.	Cubic feet per second.	Gallons per minute.	Cubic feet of water per 24 hours.	Cubic feet per second.	Gallons per minute.
September 20 to October 1	11	110,500	1.28	575	40,500	0.47	211
October 1 to 9[a]	8	640,000	7.40	3,330	152,000	1.76	794
October 9 to 16	7	248,000	2.87	1,290	29,900	.35	155
October 16 to 23	7	117,200	1.36	745	5,950	−.069	−31
	33	[b] 8,900,000			[b] 1,517,000		
Average per day		270,000	3.03	1,360	45,800	.515	232

[a] Heavy flood on October 5, 1904.
[b] Total amount contributed for each mile of the valley in thirty-three days. By converting cubic feet into acre-feet it is found that the river lost 204 acre-feet of water to the gravels of the underflow in thirty-three days, and that 34.8 acre-feet were contributed by the rainfall in the same period. These amounts are for each mile of the valley.

If the amounts shown by these figures are applied to Mesilla Valley as a whole the result is large. The valley is about 50 miles long, and if the seepage amounts to 204 acre-feet of water per mile a total of 10,200 acre-feet of water was contributed to the underflow of the valley by the river during the thirty-three days included in the table.

[a] Slichter, Charles S., Observations on the ground waters of Rio Grande Valley: Water-Sup. and Irr. Paper No. 141, U. S. Geol. Survey, 1905.

During the same time a total of 1,741 acre-feet was contributed by the rainfall, making a grand total for the valley of 11,941 acre-feet in the thirty-three days, or about 362 acre-feet a day.

No measurements are available for the valleys farther north, but judging from the uniformity of conditions throughout the region a like amount probably enters the ground in the other valleys.

ORIGIN OF UNDERFLOW.

The waters of the underflow are derived mainly from the Rio Grande. The rainfall is comparatively unimportant as a source of supply, since the rains are usually violent and of short duration, and although the material upon which the rain falls is very porous the greater part of the water enters the river. According to Slichter's table just quoted, the local rainfall contributes about one-seventh of the underflow. The tributary streams evidently contribute some water, but since they are small and intermittent the amount is probably negligible, leaving the Rio Grande as the main source of supply. Measurements of the flow of the Rio Grande demonstrate the fact that the river is continually losing water, the greater volume of flow being measured at the upstream rather than the downstream gaging stations. This is made clear by an inspection of the tables of discharge previously quoted (pp. 31–33). For purposes of convenient comparison the following table of totals is given:

Table 8.—*Discharge of the Rio Grande in acre-feet.*

	El Paso.	San Marcial.	Ildefonzo.	Cenicero.
Total for 9 years—1897–1905	6,205,066	9,168,966	10,097,307	....
Total for 6 years recorded at Cenicero	4,101,906	5,749,197	6,431,512	2,960,123

From this table it appears that during the nine years recorded a loss of 32 per cent of the flow at San Marcial occurred between San Marcial and El Paso, a distance of about 140 miles, and that within the same period a loss of 38 per cent of the Ildefonso flow, over and above the total amount entering the Rio Grande from tributary streams during those years, occurred in a distance of about 280 miles. This loss is due to evaporation, diversion for irrigation, and absorption into the gravels. It is probable that could the discharge of the tributary streams be included the loss would be about double that shown by the river alone. To illustrate: During the nine years recorded the river lost 3,892,241 acre-feet in the 280 miles between Ildefonso and El Paso, in addition to the total discharge of such important tributaries as Galisteo Creek, Rio Jemes, Rio Puerco, Arroyo Salado, and scores of smaller tributaries. It is evident that the actual loss is much greater than that indicated by measurements of river discharge alone.

An effort has been made to determine what percentage of the known loss is due to irrigation and what to seepage and evaporation. The discussion may be found in the Proceedings of the International (Water) Boundary Commission, United States and Mexico, vol. 2, pp. 405–424. The results indicate that there is a notable loss of water over and above that diverted for irrigation. An average of three comparisons (p. 417) shows that 13 per cent of the San Marcial flow was lost by seepage and evaporation above El Paso.

COURSE OF UNDERFLOW.

All known facts point to the conclusion that a large amount of water is continually passing from the river into the underflow, and must either return to the surface and evaporate or find some underground passage by which to escape. Professor Slichter's[a] investigation proves that the escape is not through the canyon at El Paso.

The débris-filled valley west of El Paso and the apparently regular gradient of its water plane suggest that the course of the underflow may be down this old valley to the basin region of northern Mexico. On the other hand, the meager data available seem to show that this gradient is lower than that for Mesilla Valley, and that the flow should be toward the river rather than away from it, as would be the case if the course of the underflow was down the old valley. The data available at the present time are not adequate to solve this problem.

A more probable means of escape is by evaporation. Accepting Slichter's measurements of 362 acre-feet a day, contributed in Mesilla Valley, about 132,000 acre-feet of water would enter the gravels in a year. The evaporation of approximately 7 feet a year would remove from the 150,000 acres of Mesilla Valley about 1,050,000 acre-feet if the water were freely exposed, or about 8 times the amount of water entering the underflow. Over a considerable part of the valley the water plane is near enough to the surface for considerable loss by capillary action.

CHEMICAL CHARACTER OF RIO GRANDE WATERS.

MESILLA DISTRICT.

A large number of chemical analyses of waters of Mesilla Valley have been published by Goss.[b] Others have been collected from various sources and preserved in the records of the United States Geological Survey. It appears from these analyses that the total solids are not high as compared with those found in waters used elsewhere for irrigation, and that the salts are not those most deleterious

[a] Slichter, C. S., ibid., pp. 9-13.

[b] Goss, Arthur, Principles of water analysis: Bull. No. 34, New Mexico College of Agric. and Mech. Arts, 1900.

to crops. "Black alkali" (Na_2CO_3) is wholly absent from both river and ground waters. "White alkali" is abundant and accumulates as incrustations of salts due to the evaporation of water brought to the surface by capillary action.

The well waters are not very satisfactory for domestic uses. The quantities of magnesium, sodium, and sulfuric acid, probably present in the form of Glauber's salt (sodium sulfate = Na_2SO_4) and Epsom salt (magnesium sulfate = $MgSO_4$), indicate that the waters of the valley in general are not very good for drinking purposes. The river water contains the same substances that are found in the wells, but in smaller amounts.

Waters obtained from the mesa gravels at El Paso, Deming, and elsewhere are much better for domestic use than those derived from gravels that are obviously supplied from the river. This is probably true of the Mesilla region, though not enough data are at hand concerning the mesa waters to permit positive statements. Two analyses have been made of samples of water taken west of Mesilla Valley. One, from J. F. Kilburn's well, contained 1,315 parts per million of dissolved solids, and is more saline than many in the valley; the other, from the railway well at Lanark, contained 585 parts per million of total solids, and is better than that from many of the valley wells.

OTHER DISTRICTS.

Little can be said of the chemical character of water from the Rio Grande region north of Mesilla Valley, few complete analyses being available. Those that could be obtained are included in Table 10. These analyses have been collected from various sources and are nearly all to be found in the records of the United States Geological Survey.

In the lowlands throughout the Rio Grande region the salts contained in the waters accumulate as white incrustations over the soil. In Albuquerque Valley these accumulations are particularly abundant and in many places prevent the growth of vegetation. This condition is probably caused by crude methods of irrigation. The land thus affected has been for many years in the possession of Mexican ranchmen, who seldom take proper care of the land.

TABLE 9.—*Analyses of Rio Grande water.*[a]

AVERAGE SAMPLES TAKEN DAILY FROM ACEQUIA NEAR AGRICULTURAL COLLEGE.

[Parts per million.]

Date.	Suspended matter.	Total solids.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Oxides of iron, aluminum, and silicon (Fe_2O_3, Al_2O_3, SiO_2).	Sulfate radicle (SO_4.)	Chlorine (Cl).	Carbonate radicle (CO_3).	White alkali.	Black alkali.
June, 1893	2,680	196	29	4	16	3	35	28	14	55	54	0
July, 1893	11,090	478	64	10	66	7	20	119	81	65	240	0
August, 1893	28,370	626	91	10	64	9	22	237	48	75	239	0
September, 1893	23,760	793	75	19	84	10	16	332	68	85	350	0
October, 1893	8,870	470	48	10	61	8	18	116	54	65	238	0
December, 1893 [b]	2,610	417	54	1	73	6	19	101	62	72	226	0
January, 1894	2,570	439	60	11	57	8	12	95	68	85	230	0
February, 1904	2,160	360	35	9	65	6	7	108	68	46	245	0
March, 1904	3,380	462	56	1	84	7	15	103	74	71	242	0
April, 1904	4,360	360	51	9	40	6	24	84	42	71	170	0
May, 1904	5,860	267	39	7	30	16	21	56	23	65	129	0
June, 1904	4,070	426	55	6	59	7	14	120	49	74	224	0
Average of Rio Grande samples for 12 months	8,314	441	59	8	58	7	19	125	54	70	221	0

SAMPLES TAKEN FROM MIDDLE OF RIVER AT EARLHAM BRIDGE.

Date.	Suspended matter.	Total solids.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Oxides of iron, aluminum, and silicon (Fe_2O_3, Al_2O_3, SiO_2).	Sulfate radicle (SO_4.)	Chlorine (Cl).	Carbonate radicle (CO_3).	White alkali.	Black alkali.
July 23, 1899	107,800	1,615	230	39	194	22	5	830	100	94	827	0
August 13, 1899	123,960	1,911	225	43	242	18	10	1,033	101	79	1,013	0
December 4, 1899	11,470	536	65	12	75	16	6	181	60	64	295	0

[a] Goss, Arthur, Principles of water analysis: Bull. No. 34, New Mexico College of Agric. and Mech. Arts, 1900, p. 72.

[b] No water in river during November.

TABLE 10.—*Analyses of well waters from the Rio Grande region.*

[Parts per million.]

Location of well.	Date of taking sample.	Total solids.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Fe_2O_3 Al_2O_3 SiO_2.	Sulfuric radicle (SO_4).	Chlorine (Cl).	Carbonic radicle (CO_3).	White alkali.	Black alkali.
Mesilla Valley.												
Agricultural College	July, 1894	6,700	131	16	54	14	16	118	60	194	255	0
Agricultural College, old pulsometer well	do	1,026	161	24	113	17	10	278	165	150	451	0
Agricultural College, old pulsometer farm well	May, 1904	960	131	28	131	18	26	251	145	194		0
Agricultural College, windmill well	Dec., 1901	1,041	181	34	136	17	25	25	133	135	621	0
Agricultural College, farm well	July, 1893	1,235	161	28	171	6	17	330	268	131	621	0
F. E. Lester, Mesilla Park	Aug., 1894	656	108	12	77	7	78	135	88	154	287	0
O. C. Snow, 2 miles west of Mesilla Park	Aug., 1894	633	105	14	74	7	5	142	76	154	287	0
Shalam Colony, 1½ miles west of Dona Ana	Aug., 1895	745	82	13	150	10	23	152	154	131	493	0
A. Goss, ¼ mile north of Agricultural College	May, 1900	1,912	246	39	282	39	7	506	399	161	936	0
1 mile northwest of Las Cruces	Oct., 1902	680	108	80	27		10	144	79	123		0
G. H. Totten, Mesilla [a]	Oct., 1904	1,566					Trace.	144	232	196		0
G. H. Totten, pumping plant [a]	do	1,123					Trace.	152	186	180		0
T. Roualt, near old Fort Filmore [a]	do	1,128	161	27	151	23	Trace.	159	176	215		0
Francisco Misques, Bosque Seco [a]	do	823	115	19	109	26	6	106	163	150		0
J. B. Barncastle, Dona Ana [a]	do	777	105	29	94	15	9	109	92	156		
La Mesa district.												
J. F. Kilburn, 9 miles west of Lanark [a]	do	1,315					Trace	109	200	315		0
Lanark, railway well		585	16	14				9	0	51		
Jornada district.												
Rincon	Sept., 1895	1,057	48	16	30	22	19	30	156	181		
Rincon, railway well		678	110	14				192		73		
Engle, railway surface well		573	40	7			Trace.	27	Trace.	165		
Engle, railway artesian well		898	4	2			Trace.	0	0	297		
San Marcial, railway well		579	86	8			Trace.	82	0	140		
Belen district.												
Belen		3,139	531	108		8	22	175	63	101		0
J. F. Chaves	Aug., 1896	2,820	443	146	76	12	33	1,420	13	172	894	
Isleta railway well		487	102	10			3	141	37	86		

[a] Samples taken by the writer and analyzed by R. F. Hare of the New Mexico experiment station.

TABLE 10.—*Analyses of well waters from the Rio Grande region*—Continued.

Location of well.	Date of taking sample.	Total solids.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Fe_2O_3 Al_2O_3 SiO_2.	Sulfuric radicle (SO_4).	Chlorine (Cl).	Carbonic radicle (CO_3).	White alkali.	Black alkali.
Albuquerque district.												
Albuquerque, city well	1905	307	41	8	40	....	68	51	15	83	....	....
University well, 1 mile east of Albuquerque	1904	213	30	8	25	....	45	28	10	70	....	....
Military well, 7 miles east of Albuquerque	1904	197	34	2	31	....	30	24	2	75	....	....
Albuquerque, railway well	....	326	61	8	....	....	....	61	....	71	....	....
Albuquerque, railway-shop well	....	365	64	13	....	....	....	36	....	106	....	....
Bernalillo, railway well	....	828	55	8	....	....	9	Trace.	Trace.	240	....	....
Thornton, railway well	....	398	60	14	....	....	Trace.	Trace.	Trace.	175	....	....
Santa Fe district.												
Santa Fe city supply, from Santa Fe Creek	May, 1899	40	5	1	4	2	10	2	1	11	10	0
Do	Jan., 1900	85	14	4	3	3	8	1	6	27	14	0

APPLICATIONS.

UTILIZATION OF UNDERFLOW.

Shallow wells.—The flood-plain material of the lowlands along the river, although saturated, does not, in general, allow the water to pass through it freely enough for the successful use of shallow irrigation wells. In certain places, however, as at Belen, where the railway well is dug in coarse sand, large volumes of water are readily obtained from this material.

Deep wells.—Beneath the fine silt of the flood plains there is coarser material, from which large quantities of water are obtained, as in the various irrigation wells in Mesilla Valley and the city wells at Albuquerque. A considerable amount of fine sand and silt occurs in the gravel beds as well as in the flood-plain deposits and prevents the rapid movement of water through them, causing the high lift and to a large extent the great cost shown in Table 6. In spite of its great cost, however, the pumping of water for irrigation has proved profitable in El Paso and Mesilla valleys. In the valleys farther north the gravels are apparently coarser and water could probably be pumped at less cost than in Mesilla Valley. In Mesilla Valley the quantity of water recovered might be greatly increased by additional wells, and pumping plants might be established with profit in Palomas, Socorro, Belen, and Albuquerque valleys. Although the data at hand show that in this region, as compared with other valleys of the Southwest, the underflow is small and the water not readily obtainable on account of the fineness of the material in which it is contained, enough water may be pumped from the sands and gravels to warrant development.

Seepage ditches.—The construction of seepage ditches as a means of obtaining the waters of the underflow has been proposed for the Rio Grande Valley, but no such ditches have been dug, and the large proportion of fine sand and silt is apparently unfavorable to this method of procuring the water.

WATER STORAGE.

The alternation of broad basins and narrow canyons along the course of the river is apparently favorable to the establishment of storage reservoirs, but at only two points are the rock formations suitable for the construction of masonry dams. These are in El Paso canyon, the dam site of the proposed International reservoir, and at Elephant Butte, the dam site of the proposed Engle reservoir.

From a geologic standpoint the Engle reservoir is much more favorable for water storage than the International reservoir. The most important geologic considerations favoring the location of a storage reservoir in Engle Valley are (1) a narrow canyon with hard rock walls; (2) rock foundation for the proposed dam; (3) good building material near the dam site, and (4) a long, deep, narrow storage reservoir, in which loss by evaporation will be comparatively small and from which the mud may to some extent be removed by sluicing.

No other good reservoir sites were found within the Rio Grande region, nor are the geologic conditions favorable to the occurrence of good sites. Since the Rio Grande Valley is a succession of débris-filled intermontane troughs it is only where the river in its superimposed course has left the old filled valleys and cut channels in the hard rock that good dam sites are found. This action has occurred at only two places in the region described—one near El Paso and one near Elephant Butte. In the other canyons the unconsolidated detritus beneath the sheets of basalt extends to some unknown depth beneath the river and prohibits the construction of bed-rock dams.

INDEX.

CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Water-Supply Paper No. 188.]

The publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists can be had on application.

Most of the above publications can be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they can be obtained, free of charge (except classes 2, 7, and 8), on application.

2. A certain number are delivered to Senators and Representatives in Congress for distribution.

3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they can be had at prices slightly above cost.

4. Copies of all Government publications are furnished to the principal public libraries in the large cities throughout the United States, where they can be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports. This paper is the one hundred and eighth in Series B, and the sixty-sixth in Series O, the complete lists of which follow (PP=Professional Paper; B=Bulletin; WS=Water-Supply Paper):

SERIES B, DESCRIPTIVE GEOLOGY.

B 23. Observations on the junction between the Eastern sandstone and the Keweenaw series on Keweenaw Point, Lake Superior, by R. D. Irving and T. C. Chamberlin. 1885. 124 pp., 17 pls. (Out of stock.)

B 33. Notes on geology of northern California, by J. S. Diller. 1886. 23 pp. (Out of stock.)

B 39. The upper beaches and deltas of Glacial Lake Agassiz, by Warren Upham. 1887. 84 pp., 1 pl. (Out of stock.)

B 40. Changes in river courses in Washington Territory due to glaciation, by Bailey Willis. 1887. 10 pp., 4 pls. (Out of stock.)

B 45. The present condition of knowledge of the geology of Texas, by R. T. Hill. 1887. 94 pp. (Out of stock.)

B 53. The geology of Nantucket, by N. S. Shaler. 1889. 55 pp., 10 pls. (Out of stock.)

B 57. A geological reconnaissance in southwestern Kansas, by Robert Hay. 1890. 49 pp., 2 pls.

B 58. The glacial boundary in western Pennsylvania, Ohio, Kentucky, Indiana, and Illinois, by G. F. Wright, with introduction by T. C. Chamberlin. 1890. 112 pp., 8 pls. (Out of stock.)

B 67. The relations of the traps of the Newark system in the New Jersey region, by N. H. Darton. 1890. 82 pp. (Out of stock.)

B 104. Glaciation of the Yellowstone Valley north of the Park, by W. H. Weed. 1893. 41 pp., 4 pls.

B 108. A geological reconnaissance in central Washington, by I. C. Russell. 1893. 108 pp., 12 pls. (Out of stock.)

B 119. A geological reconnaissance in northwest Wyoming, by G. H. Eldridge. 1894. 72 pp., 4 pls.
B 137. The geology of the Fort Riley Military Reservation and vicinity, Kansas, by Robert Hay. 1896. 35 pp., 8 pls.
B 144. The moraines of the Missouri Coteau and their attendant deposits, by J. E. Todd. 1896. 71 pp., 21 pls.
B 158. The moraines of southeastern South Dakota and their attendant deposits, by J. E. Todd. 1899. 171 pp., 27 pls.
B 159. The geology of eastern Berkshire County, Massachusetts, by B. K. Emerson. 1899. 139 pp., 9 pls.
B 165. Contributions to the geology of Maine, by H. S. Williams and H. E. Gregory. 1900. 212 pp., 14 pls.
WS 70. Geology and water resources of the Patrick and Goshen Hole quadrangles in eastern Wyoming and western Nebraska, by G. I. Adams. 1902. 50 pp., 11 pls.
B 199. Geology and water resources of the Snake River Plains of Idaho, by I. C. Russell. 1902. 192 pp., 25 pls.
PP 1. Preliminary report on the Ketchikan mining district, Alaska, with an introductory sketch of the geology of southeastern Alaska, by A. H. Brooks. 1902. 120 pp., 2 pls.
PP 2. Reconnaissance of the northwestern portion of Seward Peninsula, Alaska, by A. J. Collier. 1902. 70 pp., 11 pls.
PP 3. Geology and petrography of Crater Lake National Park, by J. S. Diller and H. B. Patton. 1902. 167 pp., 19 pls.
PP 10. Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska, by way of Dall, Kanuti, Allen, and Kowak rivers, by W. C. Mendenhall. 1902. 68 pp., 10 pls.
PP 11. Clays of the United States east of the Mississippi River, by Heinrich Ries. 1903. 298 pp., 9 pls.
PP 12. Geology of the Globe copper district, Arizona, by F. L. Ransome. 1903. 168 pp., 27 pls.
PP 13. Drainage modifications in southeastern Ohio and adjacent parts of West Virginia and Kentucky, by W. G. Tight. 1903. 111 pp., 17 pls. (Out of stock.)
B 208. Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California, by J. E. Spurr. 1903. 229 pp., 8 pls.
B 209. Geology of Ascutney Mountain, Vermont, by R. A. Daly. 1903. 122 pp., 7 pls.
WS 78. Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon, by I. C. Russell. 1903. 51 pp., 2 pls.
PP 15. Mineral resources of the Mount Wrangell district, Alaska, by W. C. Mendenhall and F. C. Schrader. 1903. 71 pp., 10 pls.
PP 17. Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian, by N. H. Darton. 1903. 69 pp., 43 pls.
B 217. Notes on the geology of southwestern Idaho and southeastern Oregon, by I. C. Russell. 1903. 83 pp., 18 pls.
B 219. The ore deposits of Tonopah, Nevada (preliminary report), by J. E. Spurr. 1903. 31 pp., 1 pl.
PP 20. A reconnaissance in northern Alaska in 1901, by F. C. Schrader. 1904. 139 pp., 16 pls.
PP 21. The geology and ore deposits of the Bisbee quadrangle, Arizona, by F. L. Ransome. 1904. 168 pp., 29 pls.
WS 90. Geology and water resources of part of the lower James River Valley, South Dakota, by J. E. Todd and C. M. Hall. 1904. 47 pp., 23 pls.
PP 25. The copper deposits of the Encampment district, Wyoming, by A. C. Spencer. 1904. 107 pp., 2 pls.
PP 26. Economic resources of the northern Black Hills, by J. D. Irving, with contributions by S. F. Emmons and T. A. Jaggar, jr. 1904. 222 pp., 20 pls.
PP 27. A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho, by Waldemar Lindgren. 1904. 122 pp., 15 pls.
PP 31. Preliminary report on the geology of the Arbuckle and Wichita mountains in Indian Territory and Oklahoma, by J. A. Taff, with an appendix on reported ore deposits in the Wichita Mountains, by H. F. Bain. 1904. 97 pp., 8 pls.
B 235. A geological reconnaissance across the Cascade Range near the forty-ninth parallel, by G. O. Smith and F. C. Calkins. 1904. 103 pp., 4 pls.
B 236. The Porcupine placer district, Alaska, by C. W. Wright. 1904. 35 pp., 10 pls.
B 237. Igneous rocks of the Highwood Mountains, Montana, by L. V. Pirsson. 1904. 208 pp., 7 pls.
B 238. Economic geology of the Iola quadrangle, Kansas, by G. I. Adams, Erasmuth Haworth, and W. R. Crane. 1904. 83 pp., 1 pl.
PP 32. Geology and underground water resources of the central Great Plains, by N. H. Darton. 1905. 433 pp., 72 pls.
WS 110. Contributions to hydrology of eastern United States, 1904; M. L. Fuller, geologist in charge. 1905. 211 pp., 5 pls.
B 242. Geology of the Hudson Valley between the Hoosic and the Kinderhook, by T. Nelson Dale. 1904. 63 pp., 3 pls.
PP 34. The Delavan lobe of the Lake Michigan glacier of the Wisconsin stage of glaciation and associated phenomena, by W. C. Alden. 1904. 106 pp., 15 pls.

PP 35. Geology of the Perry Basin in southeastern Maine, by G. O. Smith and David White. 1905. 107 pp., 6 pls.
B 243. Cement materials and industry of the United States, by E. C. Eckel. 1905. 395 pp., 15 pls.
B 246. Zinc and lead deposits of northeastern Illinois, by H. F. Bain. 1904. 56 pp., 5 pls.
B 247. The Fairhaven gold placers of Seward Peninsula, Alaska, by F. H. Moffit. 1905. 85 pp., 14 pls.
B 249. Limestones of southwestern Pennsylvania, by F. G. Clapp. 1905. 52 pp., 7 pls.
B 250. The petroleum fields of the Pacific coast of Alaska, with an account of the Bering River coal deposit, by G. C. Martin. 1905. 65 pp., 7 pls.
B 251. The gold placers of the Fortymile, Birch Creek, and Fairbanks regions, Alaska, by L. M. Prindle. 1905. 16 pp., 16 pls.
WS 118. Geology and water resources of a portion of east-central Washington, by F. C. Calkins. 1905. 96 pp., 4 pls.
B 252. Preliminary report on the geology and water resources of Central Oregon, by I. C. Russell. 1905. 138 pp., 24 pls.
PP 36. The lead, zinc, and fluorspar deposits of western Kentucky, by E. O. Ulrich and W. S. Tangier Smith. 1905. 218 pp., 15 pls.
PP 38. Economic geology of the Bingham mining district of Utah, by J. M. Boutwell, with a chapter on areal geology, by Arthur Keith, and an introduction on general geology, by S. F. Emmons. 1905. 413 pp., 49 pls.
PP 41. The geology of the central Copper River region, Alaska, by W. C. Mendenhall. 1905. 133 pp., 20 pls.
B 254. Report of progress in the geological resurvey of the Cripple Creek district, Colorado, by Waldemar Lindgren and F. L. Ransome. 1904. 36 pp.
B 255. The fluorspar deposits of southern Illinois, by H. Foster Bain. 1905. 75 pp., 6 pls.
B 256. Mineral resources of the Elders Ridge quadrangle, Pennsylvania, by R. W. Stone. 1905. 85 pp., 12 pls.
B 257. Geology and paleontology of the Judith River beds, by T. W. Stanton and J. B. Hatcher, with a chapter on the fossil plants, by F. H. Knowlton. 1905. 174 pp., 19 pls.
PP 42. Geology of the Tonopah mining district, Nevada, by J. E. Spurr. 1905. 295 pp., 24 pls.
WS 123. Geology and underground water conditions of the Jornada del Muerto, New Mexico, by C. R. Keyes. 1905. 42 pp., 9 pls.
WS 136. Underground waters of Salt River Valley, Arizona, by W. T. Lee. 1905. 194 pp., 24 pls.
PP 43. The copper deposits of Clifton-Morenci, Arizona, by Waldemar Lindgren. 1905. 375 pp., 25 pls.
B 265. Geology of the Boulder district, Colorado, by N. M. Fenneman. 1905. 101 pp., 5 pls.
B 267. The copper deposits of Missouri, by H. F. Bain and E. O. Ulrich. 1905. 52 pp., 1 pl.
PP 44. Underground water resources of Long Island, New York, by A. C. Veatch and others. 1905. 394 pp., 34 pls.
WS 148. Geology and water resources of Oklahoma, by C. N. Gould. 1905. 178 pp., 22 pls.
B 270. The configuration of the rock floor of Greater New York, by W. H. Hobbs. 1905. 96 pp., 5 pls.
B 272. Taconic physiography, by T. M. Dale. 1905. 52 pp., 14 pls.
PP 45. The geography and geology of Alaska, a summary of existing knowledge, by A. H. Brooks, with a section on climate, by Cleveland Abbe, jr., and a topographic map and description thereof, by R. M. Goode. 1905. 327 pp., 34 pls.
B 273. The drumlins of southeastern Wisconsin (preliminary paper), by W. C. Alden. 1905. 46 pp., 9 pls.
PP 46. Geology and underground water resources of northern Louisiana and southern Arkansas, by A. C. Veatch. 1906. 422 pp., 51 pls.
PP 49. Geology and mineral resources of part of the Cumberland Gap coal field, Kentucky, by G. H. Ashley and L. C. Glenn, in cooperation with the State Geological Department of Kentucky, C. J. Norwood, curator. 1906. 239 pp., 40 pls.
PP 50. The Montana lobe of the Keewatin ice sheet, by F. H. H. Calhoun. 1906. 62 pp., 7 pls.
B 277. Mineral resources of Kenai peninsula, Alaska: Gold fields of the Turnagain Arm region, by F. H. Moffit; and the coal fields of the Kachemak Bay region, by R. W. Stone. 1906. 80 pp., 18 pls. (Out of stock.)
WS 154. The geology and water resources of the eastern portion of the Panhandle of Texas, by C. N. Gould. 1906. 64 pp., 15 pls.
B 278. Geology and coal resources of the Cape Lisburne region, Alaska, by A. J. Collier. 1906. 54 pp., 9 pls.
B 279. Mineral resources of the Kittanning and Rural Valley quadrangles, Pennsylvania, by Charles Butts. 1906. 198 pp., 11 pls.
B 280. The Rampart gold placer region, Alaska, by L. M. Prindle and F. L. Hess. 1906. 54 pp., 7 pls.
B 282. Oil fields of the Texas-Louisiana Gulf Coastal Plain, by N. M. Fenneman. 1906. 146 pp., 11 pls.
WS 157. Underground water in the valleys of Utah Lake and Jordan River, Utah, by G. B. Richardson. 1906. 81 pp., 9 pls.
PP 51. Geology of the Bighorn Mountains, by N. H. Darton. 1906. 129 pp., 47 pls.
WS 158. Preliminary report on the geology and underground waters of the Roswell artesian area, New Mexico, by C. A. Fisher. 1906. 29 pp., 9 pls.

PP 52. Geology and underground waters of the Arkansas Valley in eastern Colorado, by N. H. Darton. 1906. 90 pp., 28 pls.

WS 159. Summary of underground-water resources of Mississippi, by A. F. Crider and L. C. Johnson. 1906. 86 pp., 6 pls.

PP 53. Geology and water resources of the Bighorn basin, Wyoming, by Cassius A. Fisher. 1906. 72 pp., 16 pls.

B 283. Geology and mineral resources of Mississippi, by A. F. Crider. 1906. 99 pp., 4 pls.

B 286. Economic geology of the Beaver quadrangle, Pennsylvania (southern Beaver and northwestern Allegheny counties), by L. H. Woolsey. 1906. 132 pp., 8 pls.

B 287. The Juneau gold belt, Alaska, by A. C. Spencer, and a reconnaissance of Admiralty Island, Alaska, by C. W. Wright. 1906. 161 pp., 37 pls.

PP 54. The geology and gold deposits of the Cripple Creek district, Colorado, by W. Lindgren and F. L. Ransome. 1906. 516 pp., 29 pls.

PP 55. Ore deposits of the Silver Peak quadrangle, Nevada, by J. E. Spurr. 1906. 174 pp., 24 pls.

B 289. A reconnaissance of the Matanuska coal field, Alaska, in 1905, by G. C. Martin. 1906. 36 pp., 5 pls.

WS 164. Underground waters of Tennessee and Kentucky west of Tennessee River and of an adjacent area in Illinois, by L. C. Glenn. 1906. 173 pp., 7 pls.

B 293. A reconnaissance of some gold and tin deposits of the southern Appalachians, by L. C. Groton, with notes on the Dahlonega mines, by W. Lindgren. 1906. 134 pp., 9 pls.

B 294. Zinc and lead deposits of the upper Mississippi Valley, by H. Foster Bain. 1906. 155 pp., 16 pls.

B295. The Yukon-Tanana region, Alaska: Description of Circle quadrangle, by L. M. Prindle. 1906. 27 pp., 1 pl.

B 296. Economic geology of the Independence quadrangle, Kansas, by Frank C. Schrader and Erasmus Haworth. 1906. 74 pp., 6 pls.

WS 181. Geology and water resources of Owens Valley, California, by Willis T. Lee. 1906. 28 pp., 6 pls.

B 297. The Yampa coal field, Routt County, Colo., by N. M. Fenneman, Hoyt S. Gale, and M. R. Campbell. 1906. 96 pp., 9 pls.

B 300. Economic geology of the Amity quadrangle in eastern Washington County, Pa., by F. G. Clapp. 1906. — pp., 8 pls.

B 303. Preliminary account of Goldfield, Bullfrog, and other mining districts in southern Nevada, by F. L. Ransome, with notes on the Manhattan district, by G. H. Garrey and W. H. Emmons. 1906. — pp., 5 pls.

B 304. Oil and gas fields of Greene County, Pa., by R. W. Stone and F. G. Clapp. 1906. 110 pp., 3 pls.

WS 188. Water resources of the Rio Grande Valley in New Mexico and their development, by W. T. Lee. 1906. 59 pp., 10 pls.

SERIES O, UNDERGROUND WATERS.

WS 4. A reconnaissance in southeastern Washington, by I. C. Russell. 1897. 96 pp., 7 pls. (Out of stock.)

WS 6. Underground waters of southwestern Kansas, by Erasmus Haworth. 1897. 65 pp., 12 pls. (Out of stock.)

WS 7. Seepage waters of northern Utah, by Samuel Fortier. 1897. 50 pp., 3 pls. (Out of stock.)

WS 12. Underground waters of southeastern Nebraska, by N. H. Darton. 1898. 56 pp., 21 pls. (Out of stock.)

WS 21. Wells of northern Indiana, by Frank Leverett. 1899. 82 pp., 2 pls. (Out of stock.)

WS 26. Wells of southern Indiana (continuation of No. 21), by Frank Leverett. 1899. 64 pp. (Out of stock.)

WS 30. Water resources of the lower peninsula of Michigan, by A. C. Lane. 1899. 97 pp., 7 pls. (Out of stock.)

WS 31. Lower Michigan mineral waters, by A. C. Lane. 1899. 97 pp., 4 pls. (Out of stock.)

WS 34. Geology and water resources of a portion of southeastern South Dakota, by J. E. Todd. 1900. 34 pp., 19 pls.

WS 53. Geology and water resources of Nez Perces County, Idaho, Pt. I, by I. C. Russell. 1901. 86 pp., 10 pls. (Out of stock.)

WS 54. Geology and water resources of Nez Perces County, Idaho, Pt. II, by I. C. Russell. 1901. 87-141 pp. (Out of stock.)

WS 55. Geology and water resources of a portion of Yakima County, Wash., by G. O. Smith. 1901. 68 pp., 7 pls. (Out of stock.)

WS 57. Preliminary list of deep borings in the United States, Pt. I, by N. H. Darton. 1902. 60 pp. (Out of stock.)

WS 59. Development and application of water in southern California, Pt. I, by J. B. Lippincott. 1902. 95 pp., 11 pls. (Out of stock.)

WS 60. Development and application of water in southern California, Pt. II, by J. B. Lippincott. 1902. 96-140 pp. (Out of stock.)

WS 61. Preliminary list of deep borings in the United States, Pt. II, by N. H. Darton. 1902. 67 pp. (Out of stock.)

WS 67. The motions of underground waters, by C. S. Slichter. 1902. 106 pp., 8 pls. (Out of stock.)

B 199. Geology and water resources of the Snake River Plains of Idaho, by I. C. Russell. 1902. 192 pp., 25 pls.

WS 77. Water resources of Molokai, Hawaiian Islands, by Waldemar Lindgren. 1903. 62 pp., 4 pls.

WS 78. Preliminary report on artesian basin in southwestern Idaho and southeastern Oregon, by I. C. Russell. 1903. 53 pp., 2 pls.

PP 17. Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian, by N. H. Darton. 1903. 69 pp., 43 pls.

WS 90. Geology and water resources of a part of the lower James River Valley, South Dakota, by J. E. Todd and C. M. Hall. 1904. 47 pp., 23 pls.

WS 101. Underground waters of southern Louisiana, by G. D. Harris, with discussions of their uses for water supplies and for rice irrigation, by M. L. Fuller. 1904. 98 pp., 11 pls.

WS 102. Contributions to the hydrology of eastern United States, 1903, by M. L. Fuller. 1904. 522 pp.

WS 104. Underground waters of Gila Valley, Arizona, by W. T. Lee. 1904. 71 pp., 5 pls.

WS 106. Water resources of the Philadelphia district, by Florence Bascom. 1904. 75 pp., 4 pls.

WS 110. Contributions to the hydrology of eastern United States, 1904; M. L. Fuller, geologist in charge. 1904. 211 pp., 5 pls.

PP 32. Geology and underground water resources of the central Great Plains, by N. H. Darton. 1904. 433 pp., 72 pls. (Out of stock.)

WS 111. Preliminary report on underground waters of Washington, by Henry Landes. 1904. 85 pp., 1 pl.

WS 112. Underflow tests in the drainage basin of Los Angeles River, by Homer Hamlin. 1904. 55 pp., 7 pls.

WS 114. Underground waters of eastern United States; M. L. Fuller, geologist in charge. 1904. 285 pp., 18 pls.

WS 118. Geology and water resources of east-central Washington, by F. C. Calkins. 1905. 96 pp., 4 pls.

B 252. Preliminary report on the geology and water resources of central Oregon, by I. C. Russell. 1905. 138 pp., 24 pls.

WS 120. Bibliographic review and index of papers relating to underground waters, published by the United States Geological Survey, 1879–1904, by M. L. Fuller. 1905. 128 pp.

WS 122. Relation of the law to underground waters, by D. W. Johnson. 1905. 55 pp.

WS 123. Geology and underground water conditions of the Jornada del Muerto, New Mexico, by C. R. Keyes. 1905. 42 pp., 9 pls.

WS 136. Underground waters of the Salt River Valley, by W. T. Lee. 1905. 194 pp., 24 pls.

B 264. Record of deep-well drilling for 1904, by M. L. Fuller, E. F. Lines, and A. C. Veatch. 1905. 106 pp.

PP 44. Underground water resources of Long Island, New York, by A. C. Veatch and others. 1905. 394 pp., 34 pls.

WS 137. Development of underground waters in the eastern coastal plain region of southern California, by W. C. Mendenhall. 1905. 140 pp., 7 pls.

WS 138. Development of underground waters in the central coastal plain region of southern California, by W. C. Mendenhall. 1905. 162 pp., 5 pls.

WS 139. Development of underground waters in the western coastal plain region of southern California, by W. C. Mendenhall. 1905. 105 pp., 7 pls.

WS 140. Field measurements of the rate of movement of underground waters, by C. S. Slichter. 1905. 122 pp., 15 pls.

WS 141. Observations on the ground waters of Rio Grande Valley, by C. S. Slichter. 1905. 83 pp., 5 pls.

WS 142. Hydrology of San Bernardino Valley, California, by W. C. Mendenhall. 1905. 124 pp., 13 pls.

WS 145. Contributions to the hydrology of eastern United States, M. L. Fuller, geologist in charge. 1905. 220 pp., 6 pls.

WS 148. Geology and water resources of Oklahoma, by C. N. Gould. 1905. 178 pp., 22 pls.

WS 149. Preliminary list of deep borings in the United States, second edition, with additions, by N. H. Darton. 1905. 175 pp.

PP 46. Geology and underground water resources of northern Louisiana and southern Arkansas, by A. C. Veatch. 1906 422 pp , 51 pls.

WS 153. The underflow in Arkansas Valley in western Kansas, by C. S. Slichter. 1906. 90 pp., 3 pls.

WS 154. The geology and water resources of the eastern portion of the Panhandle of Texas, by C. N. Gould. 1906. 64 pp., 15 pls.

WS 155. Fluctuations of the water level in wells, with special reference to Long Island, New York, by A. C. Veatch. 1906. 83 pp., 9 pls.

WS 157. Underground water in the valleys of Utah Lake and Jordan River, Utah, by G. B. Richardson. 1906. 81 pp., 9 pls.

WS 158. Preliminary report on the geology and underground waters of the Roswell artesian area, New Mexico, by C. A. Fisher. 1906. 29 pp., 9 pls.

PP 52. Geology and underground waters of the Arkansas Valley in eastern Colorado, by N. H. Darton. 1906. 90 pp., 28 pls.

WS 159. Summary of underground-water resources of Mississippi, by A. F. Crider and L. C. Johnson. 1906. 86 pp., 6 pls.

PP 53. Geology and water resources of the Bighorn basin, Wyoming, by C. A. Fisher. 1906. 72 pp., 16 pls.

WS 160. Underground-water papers, 1906, by M. L. Fuller. 1906. 104 pp., 1 pl.

WS 163. Bibliographic review and index of underground-water literature published in the United States in 1905, by M. L. Fuller, F. G. Clapp, and B. L. Johnson. 1906. 130 pp.

WS 164. Underground waters of Tennessee and Kentucky west of Tennessee River and of an adjacent area in Illinois, by L. C. Glenn. 1906. 173 pp., 7 pls.

WS 181. Geology and water resources of Owens Valley, California, by W. T. Lee. 1906. 28 pp., 6 pls.

WS 182. Flowing wells and municipal water supplies in the southern portion of the Southern Peninsula of Michigan, by Frank Leverett and others. 1906. 292 pp., 5 pls.

WS 183. Flowing wells and municipal water supplies in the middle and northern portions of the Southern Peninsula of Michigan, by Frank Leverett and others. 1906. 393 pp., 5 pls.

B 298. Record of deep-well drilling for 1905, by M. L. Fuller and Samuel Sanford. 1906. 299 pp.

WS 184. The underflow of the South Platte Valley, by C. S. Slichter and H. C. Wolff. 1906. 42 pp.

WS 188. Water resources of the Rio Grande Valley in New Mexico and their development, by W. T. Lee. 1906. 59 pp., 10 pls.

The following papers also relate to this subject: Underground waters of Arkansas Valley in eastern Colorado, by G. K. Gilbert, in Seventeenth Annual, Pt. II; Preliminary report on artesian waters of a portion of the Dakotas, by N. H. Darton, in Seventeenth Annual, Pt. II; Water resources of Illinois, by Frank Leverett, in Seventeenth Annual, Pt. II; Water resources of Indiana and Ohio, by Frank Leverett, in Eighteenth Annual, Pt. IV; New developments in well boring and irrigation in eastern South Dakota, by N. H. Darton, in Eighteenth Annual, Pt. IV; Rock waters of Ohio, by Edward Orton, in Nineteenth Annual, Pt. IV; Artesian-well prospects in the Atlantic coastal plain region, by N. H. Darton, Bulletin No. 138.

Correspondence should be addressed to

THE DIRECTOR,
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

JANUARY, 1907.

O